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Shafer et al.

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(54) **PUMP DEVICES**

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(51) **Int. Cl.**

F04D 13/02	(2006.01)
F04D 13/06	(2006.01)
F04D 29/24	(2006.01)
F04D 29/046	(2006.01)

(52) **U.S. Cl.**

CPC ***F04D 13/027*** (2013.01); ***F04D 13/06*** (2013.01); ***F04D 29/046*** (2013.01); ***F04D 29/24*** (2013.01); *F04C 2240/20* (2013.01); *F04C 2240/30* (2013.01); *F04C 2240/40* (2013.01); *F04C 2240/56* (2013.01)

(58) **Field of Classification Search**

CPC F04D 13/027; F04D 13/06; F04D 29/046; F04D 29/24

See application file for complete search history.

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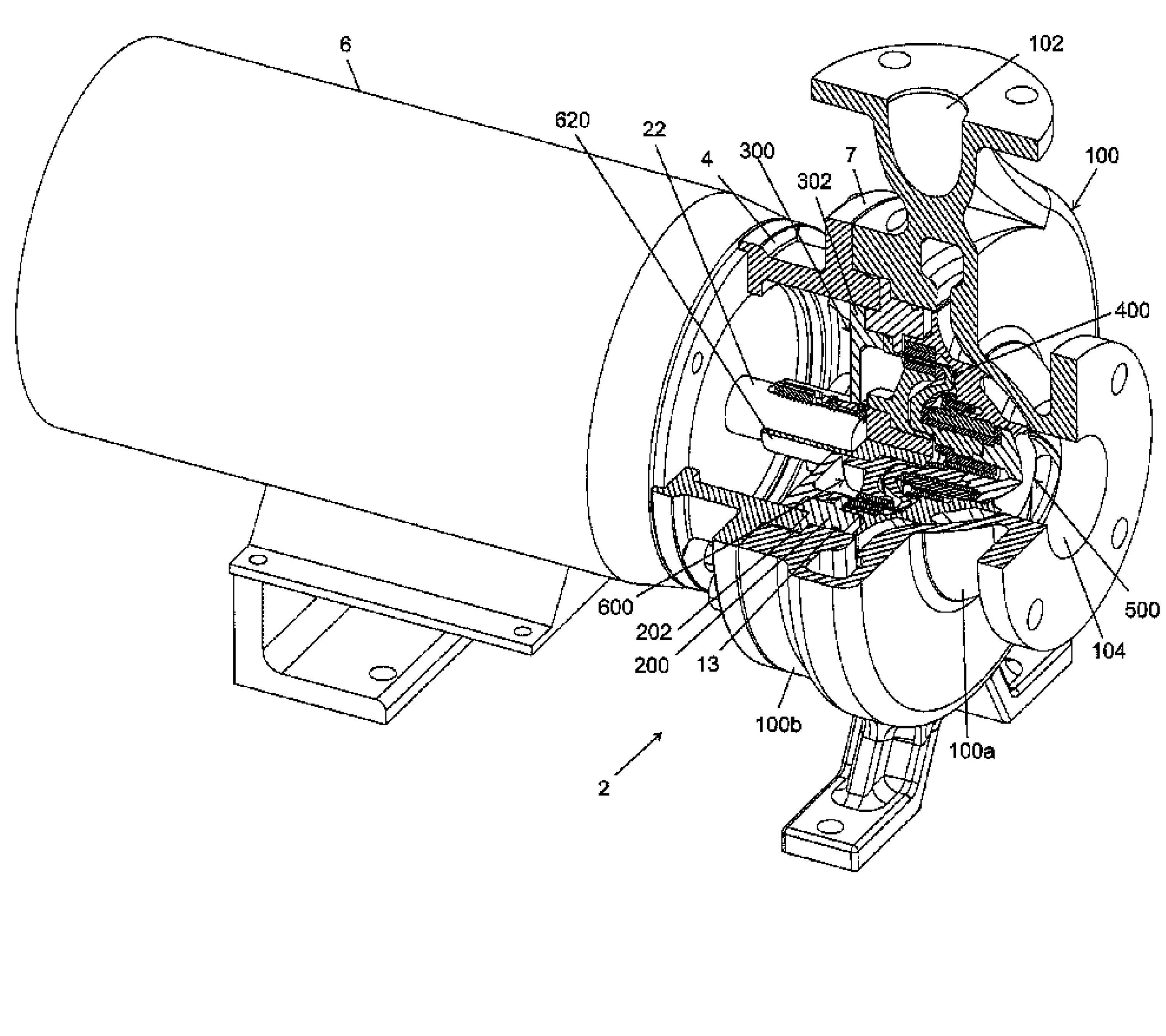
(57) **ABSTRACT**

The disclosure provides pumps that include improvements in construction, which involve bearing surfaces, recirculation paths, mounting footprints, impeller vane starting diameters, canister assemblies, and rotor assembly bushing configurations.

20 Claims, 18 Drawing Sheets



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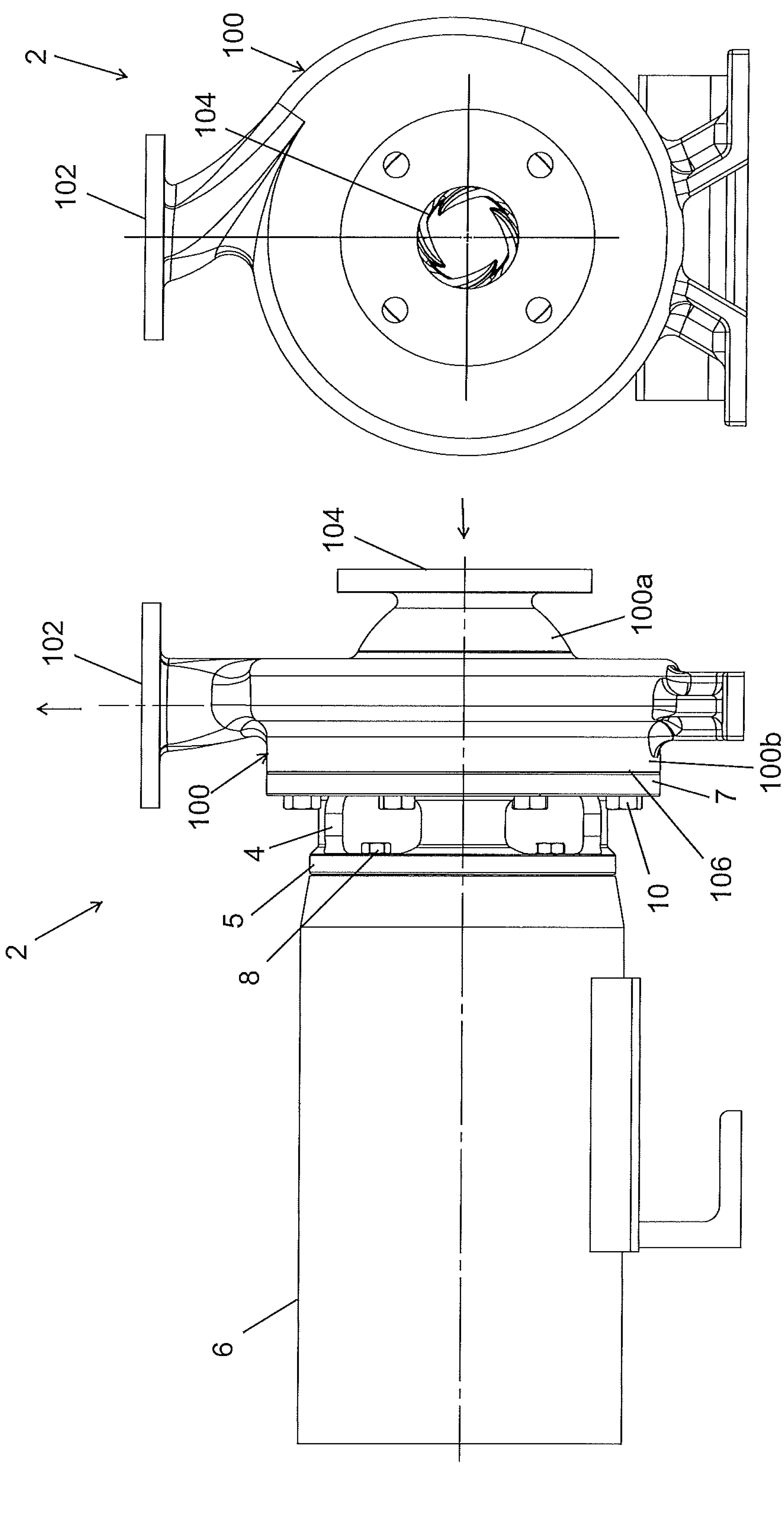

FIG. 1

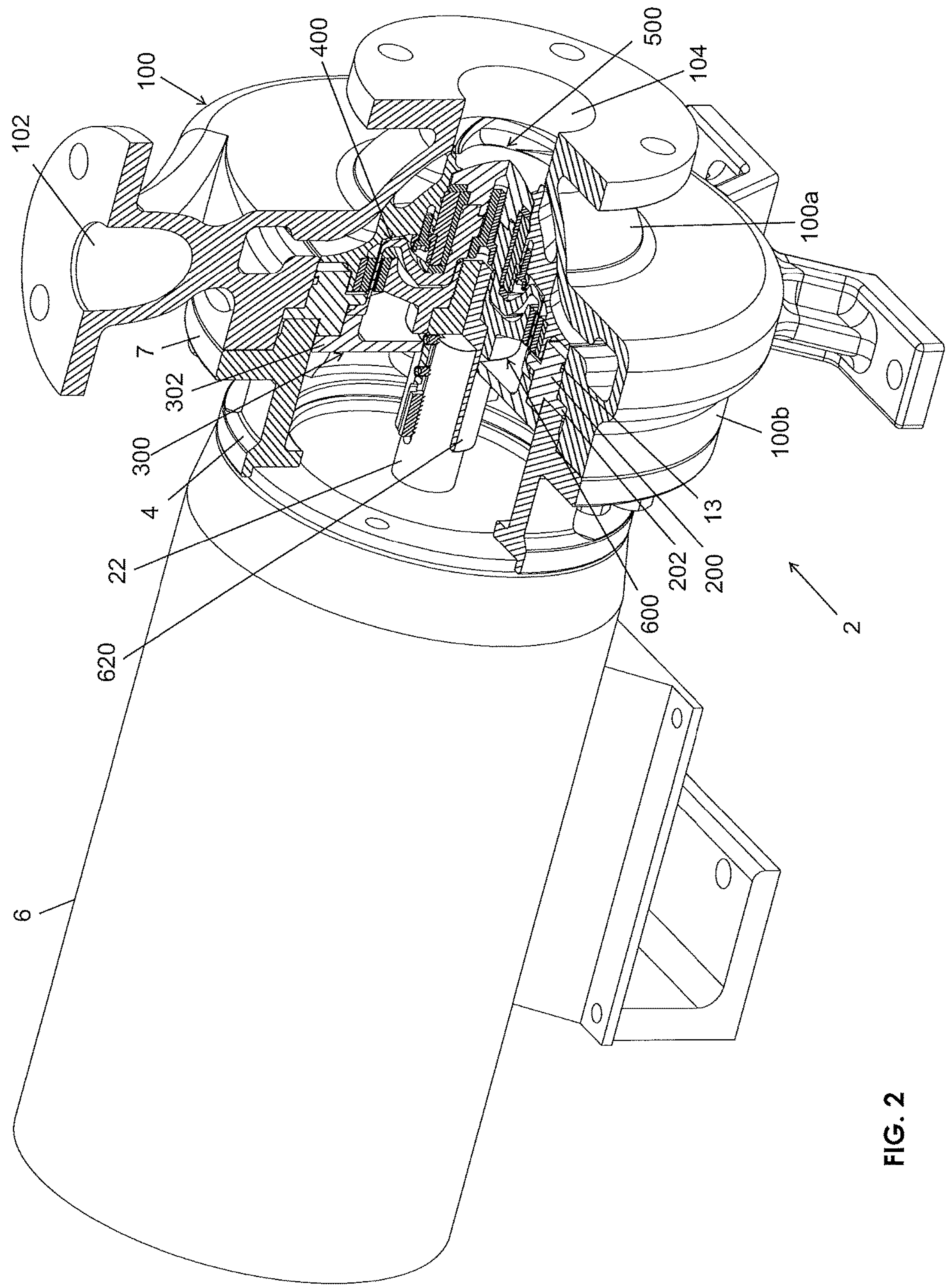

FIG. 2

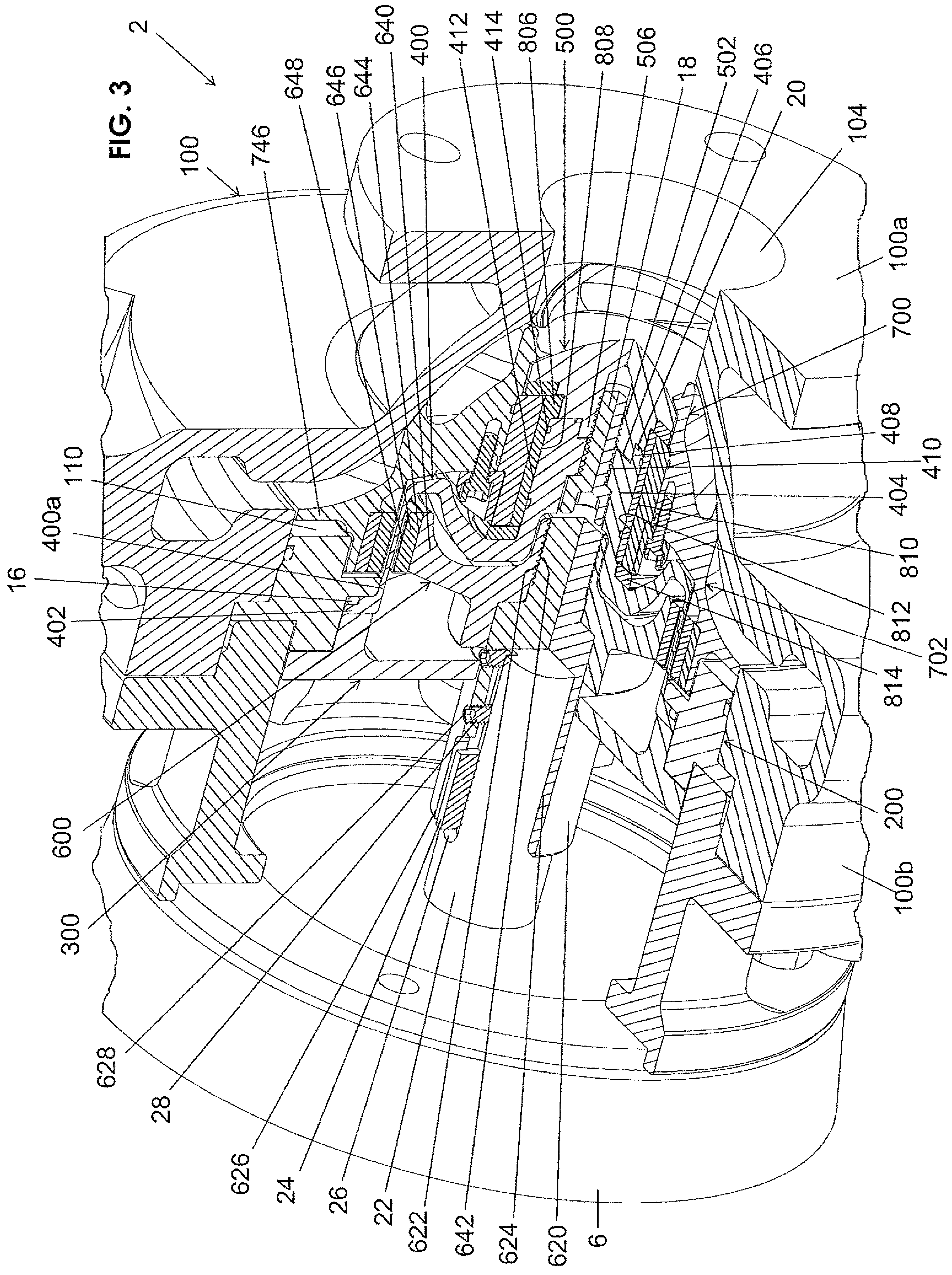
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FIG. 3

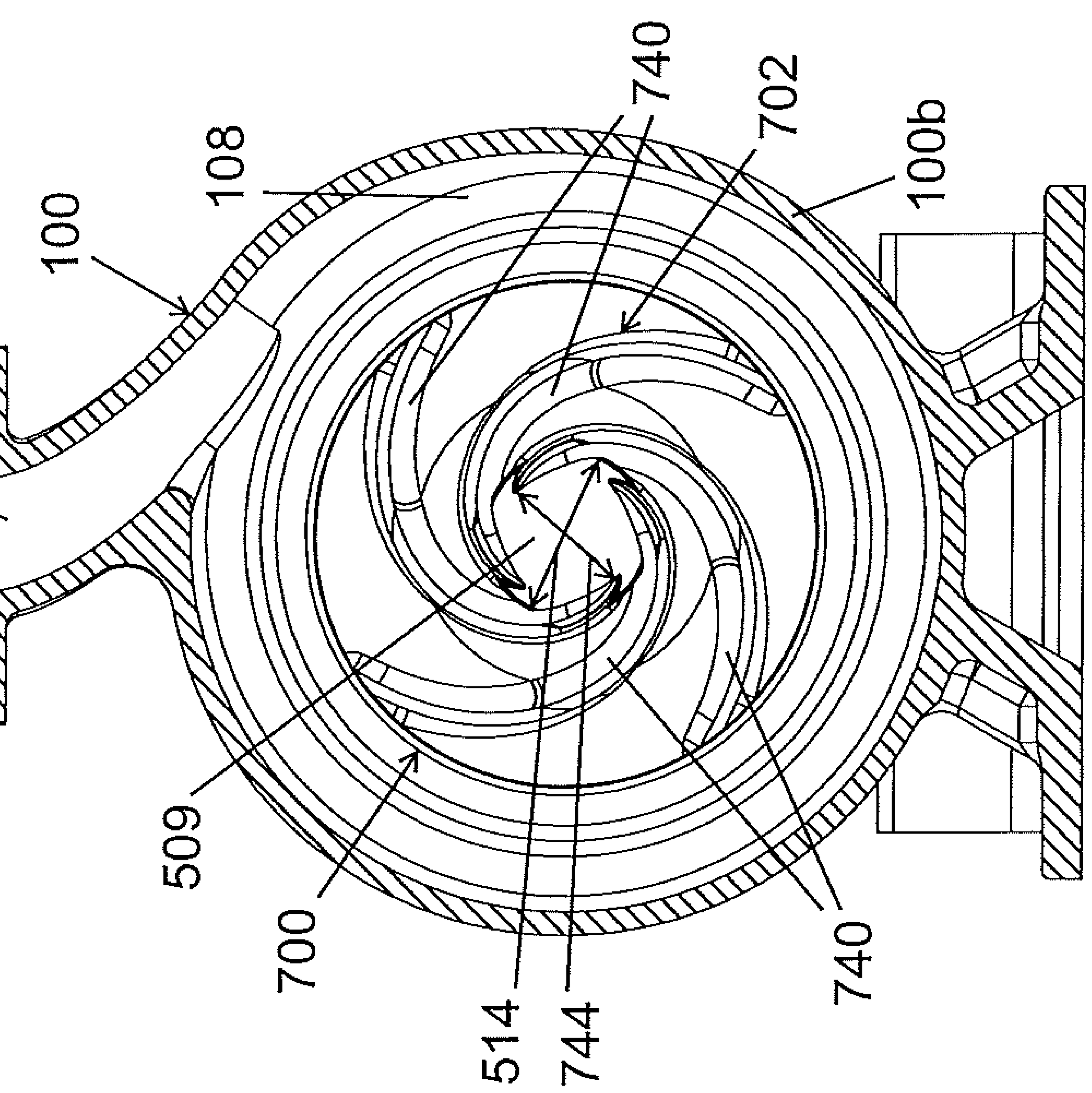
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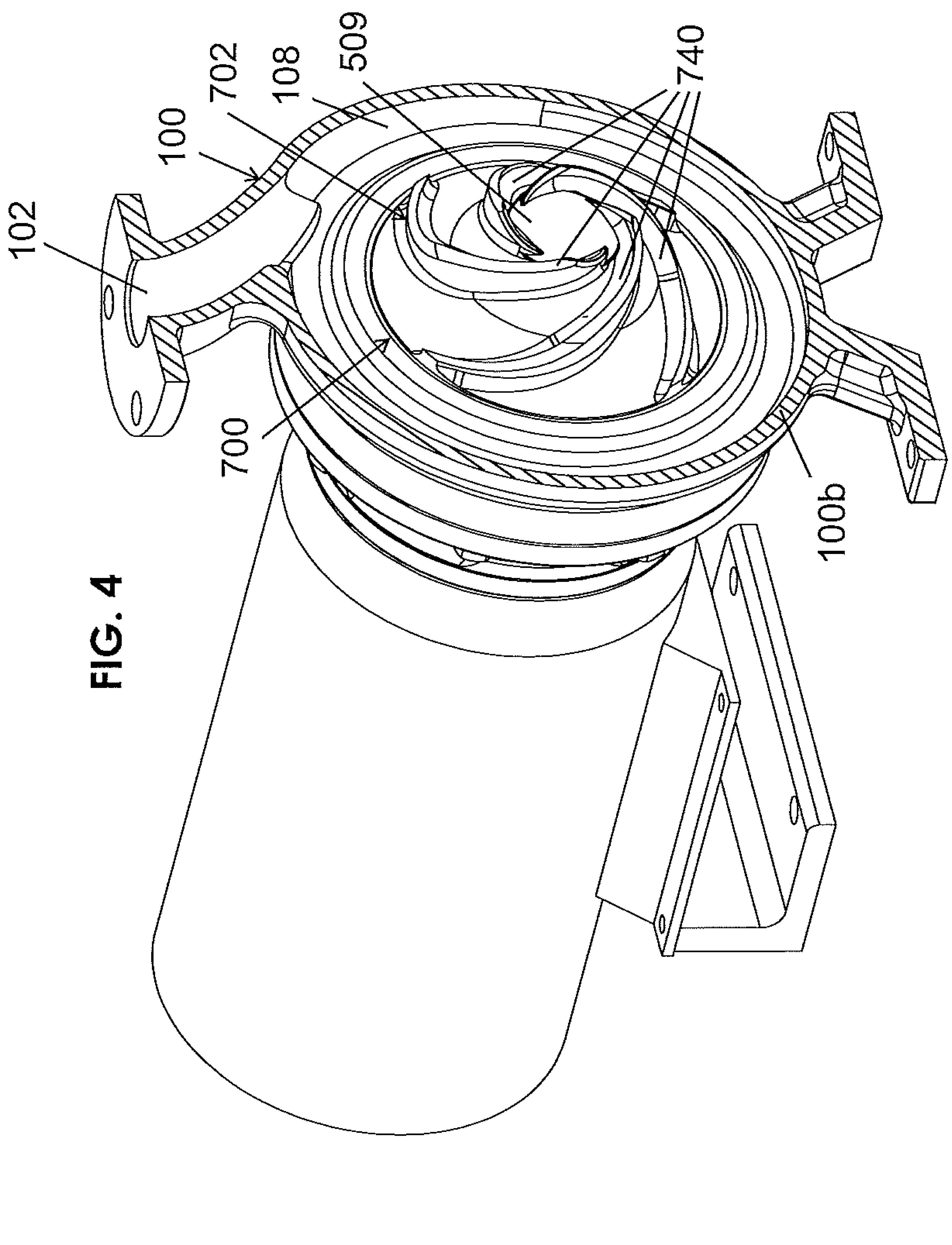
FIG. 5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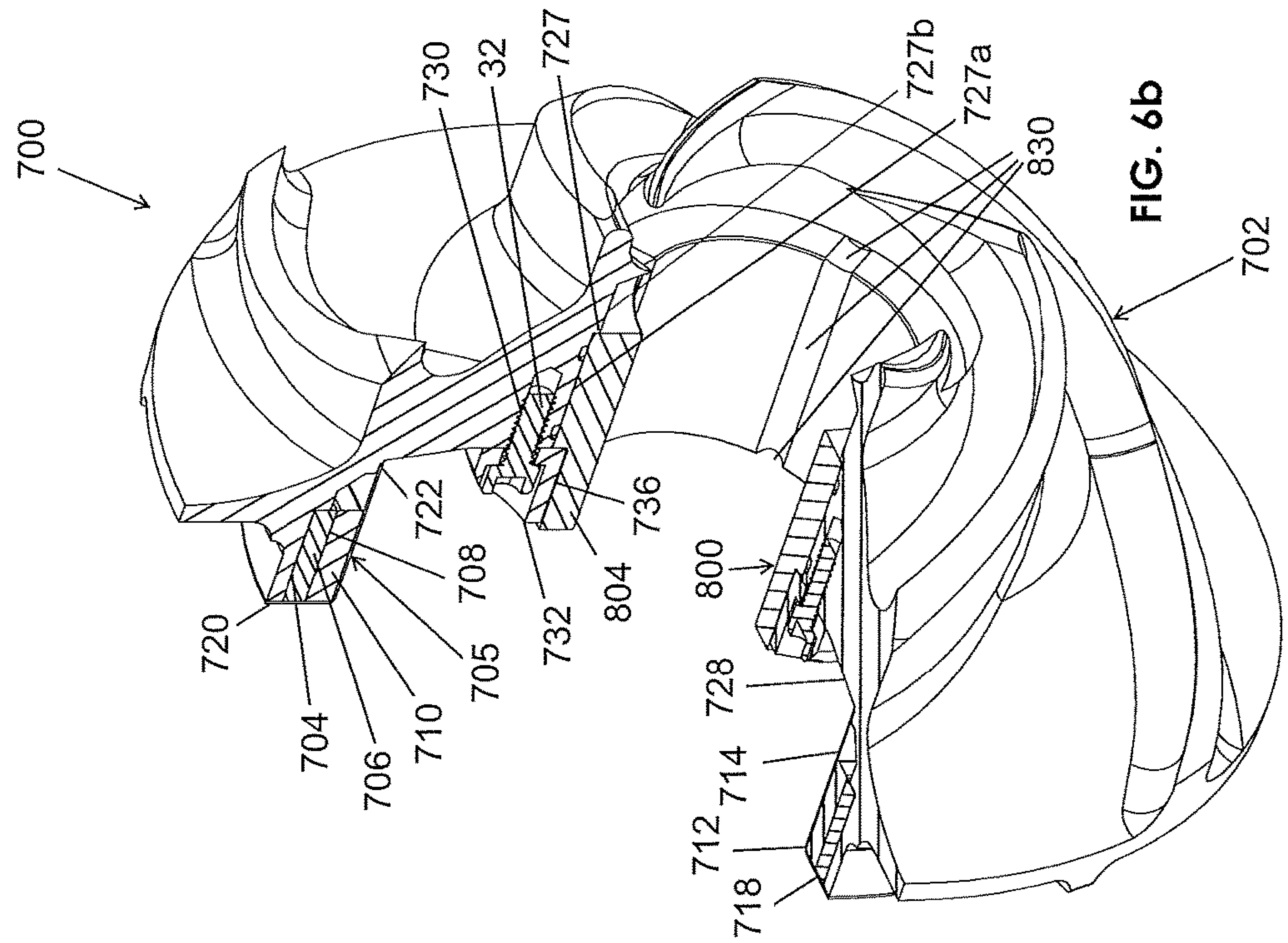
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718

FIG. 6b

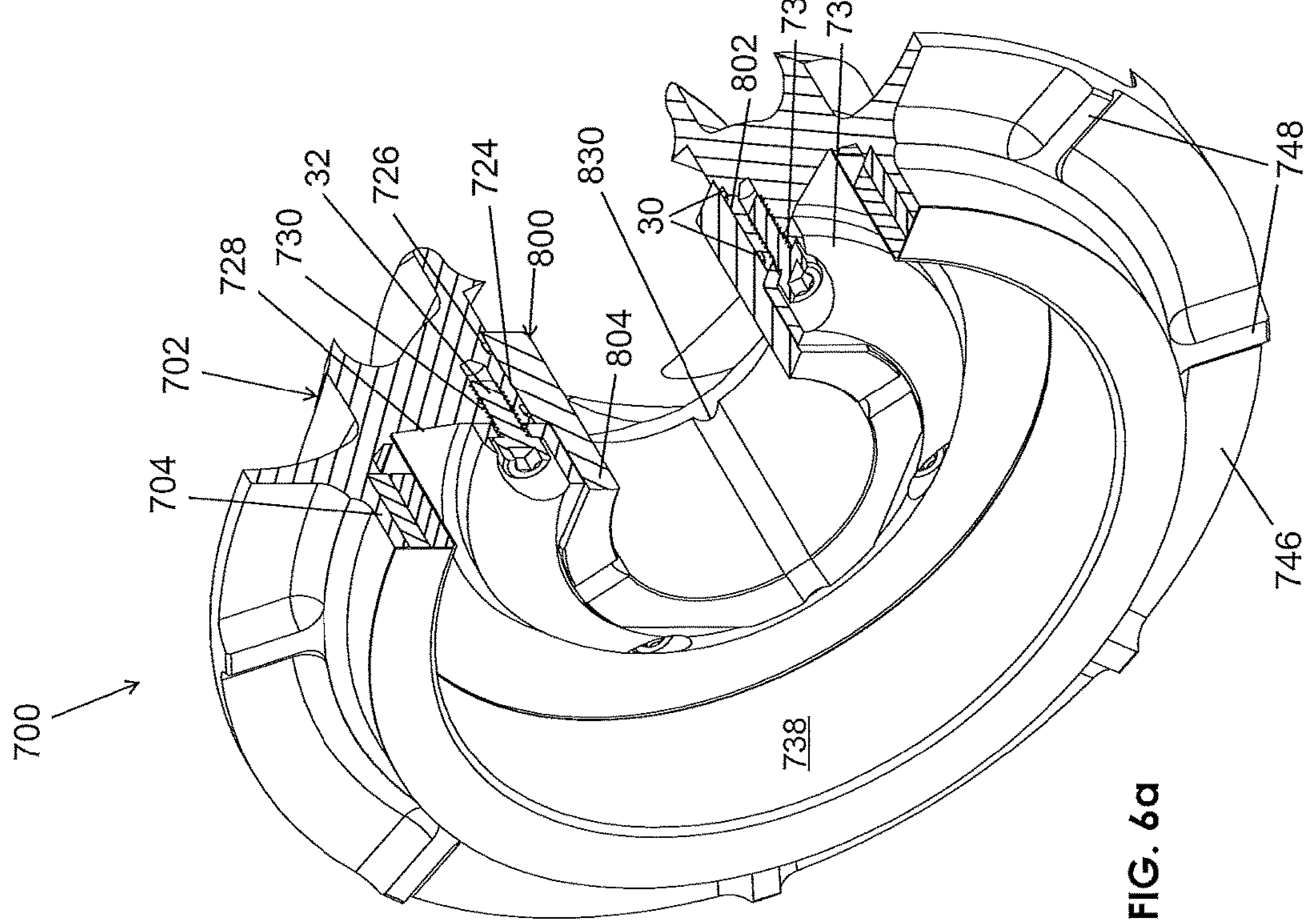
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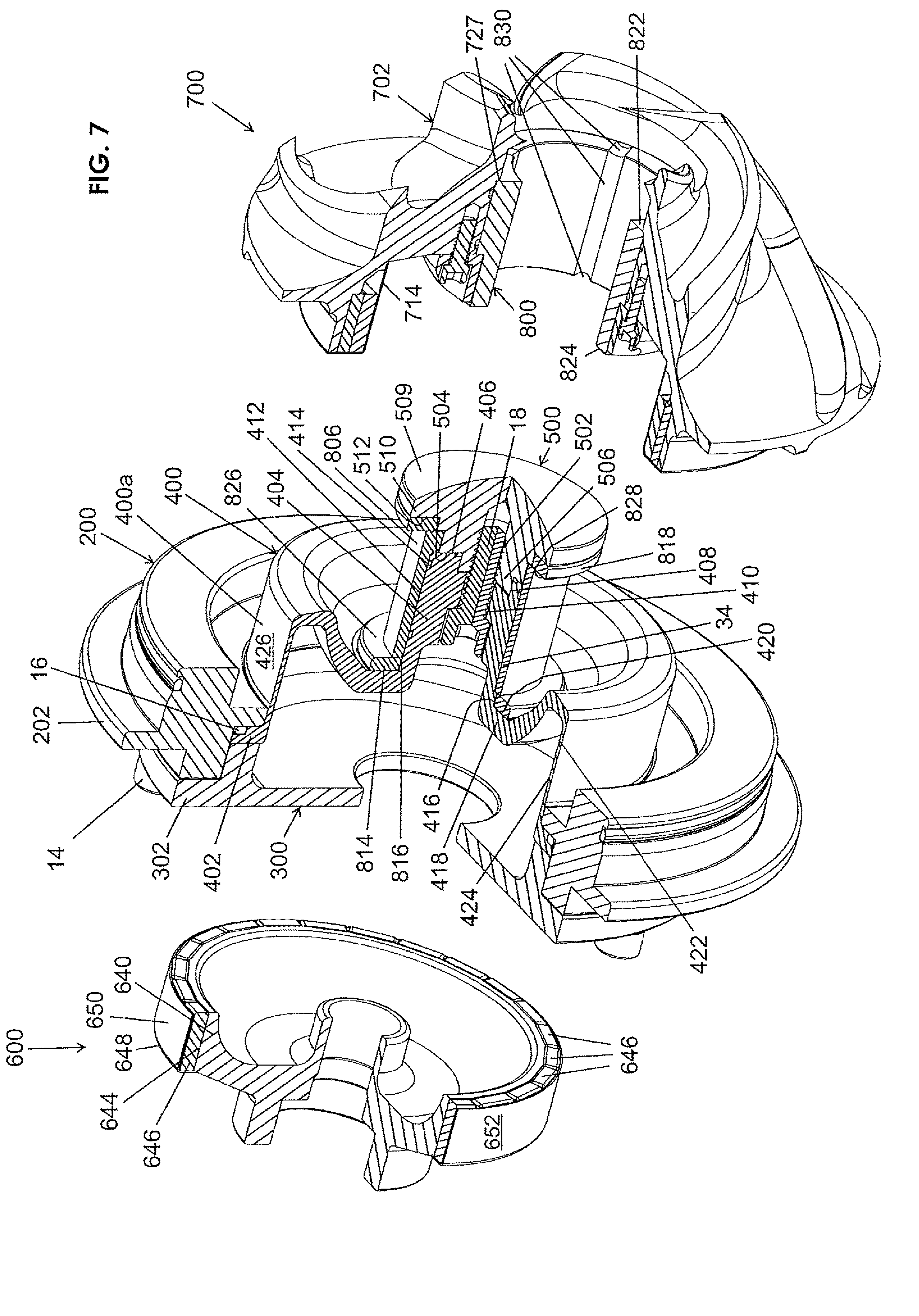
FIG. 6a

FIG. 7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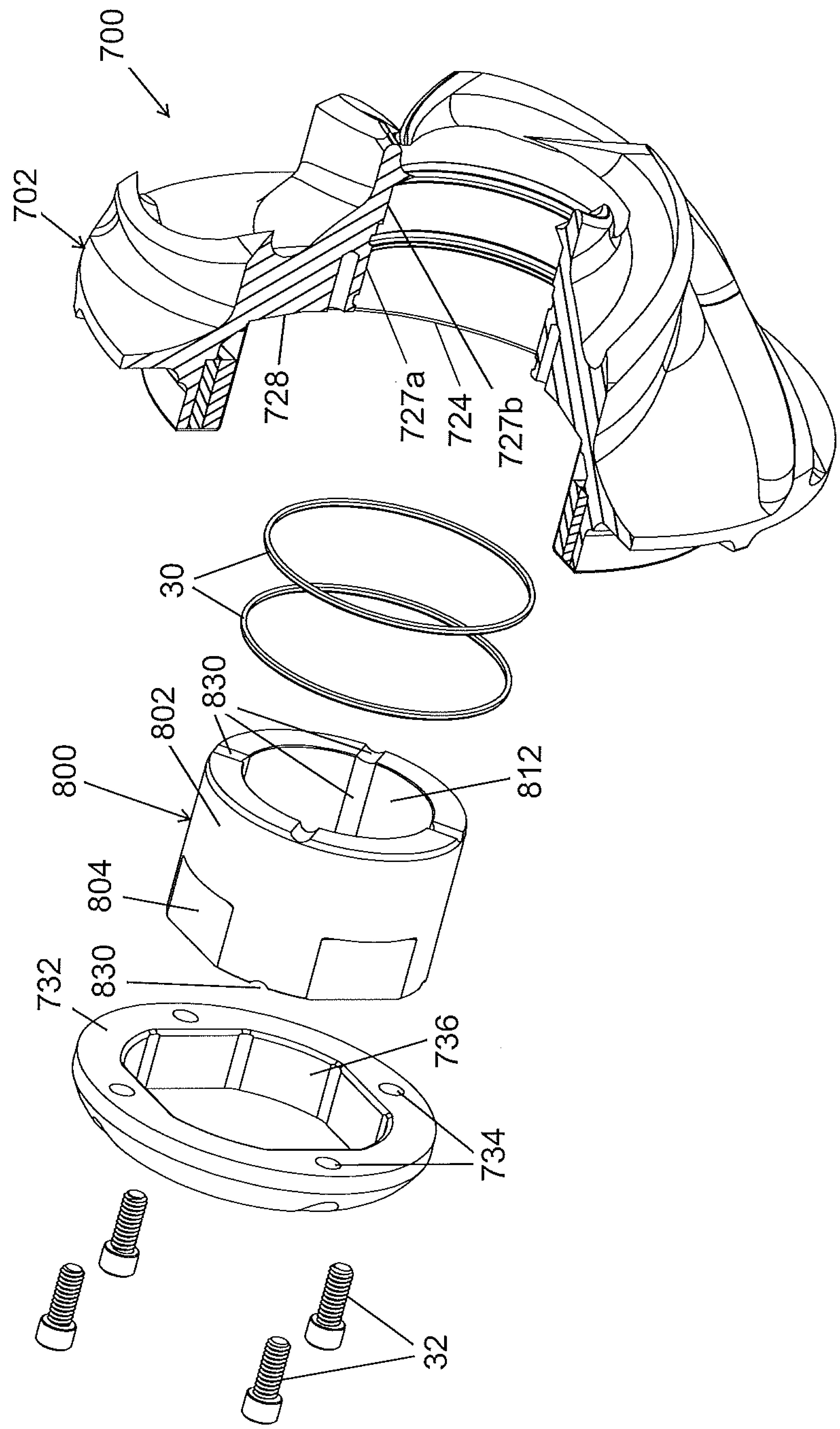
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FIG. 8

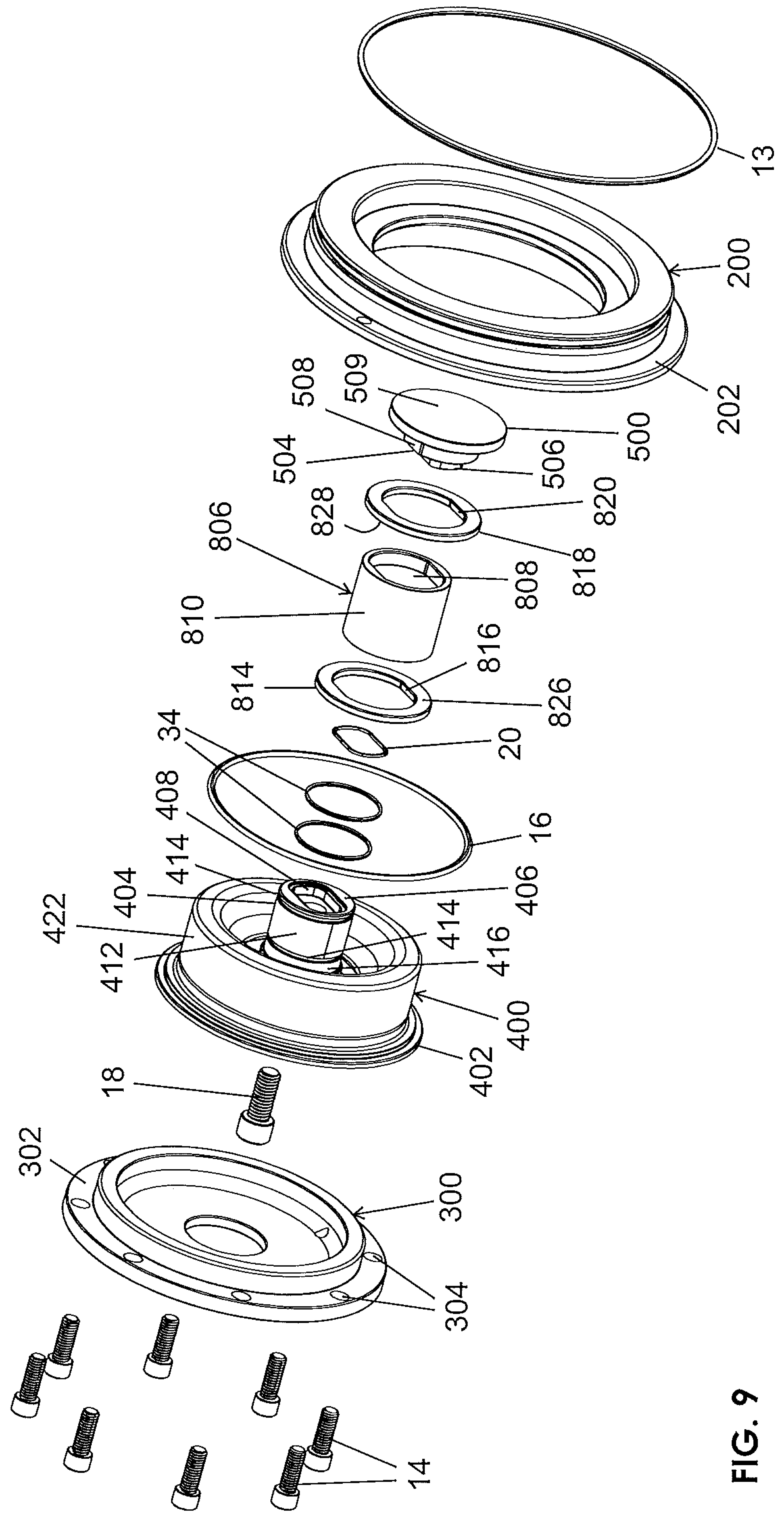
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FIG. 9

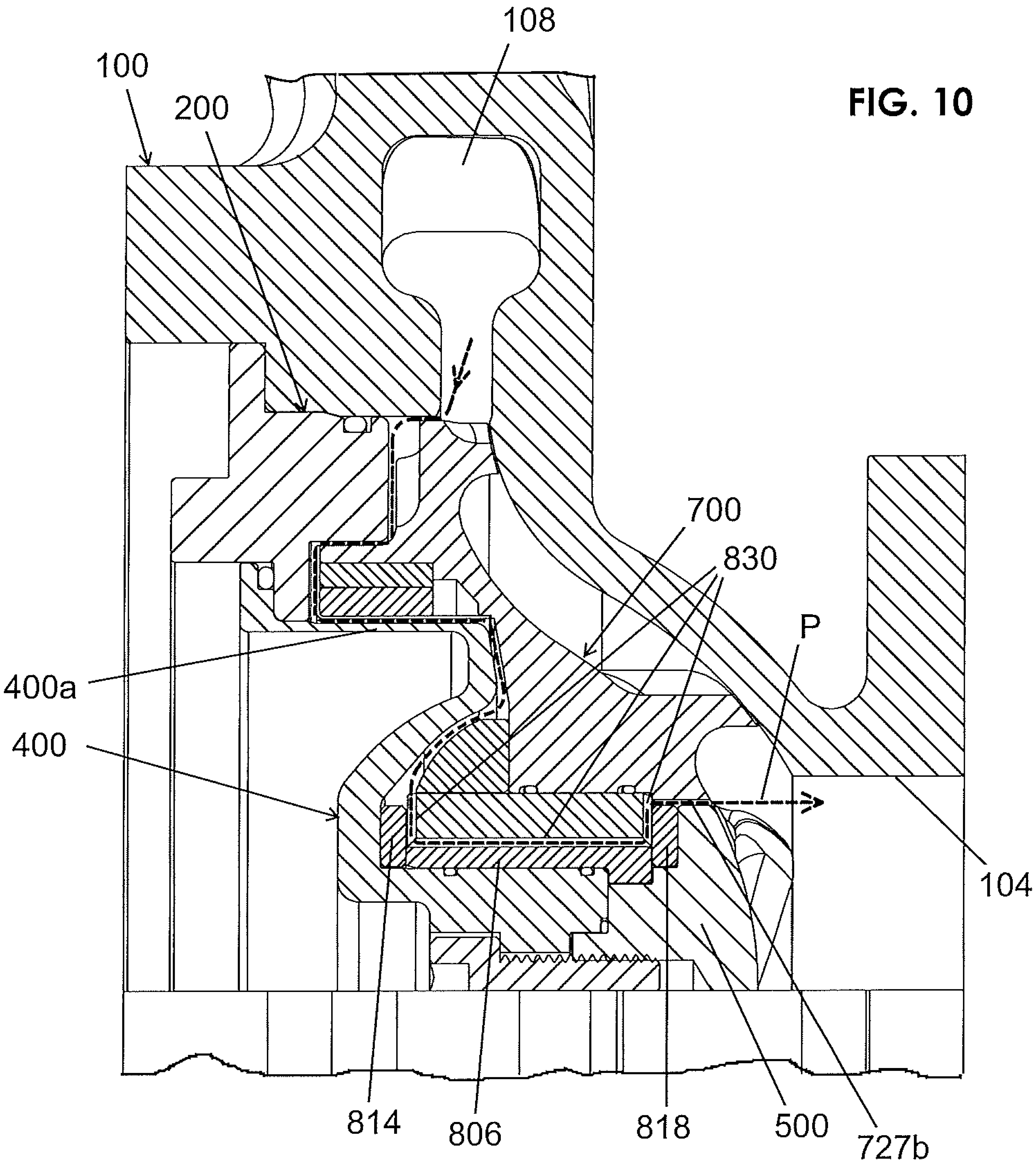
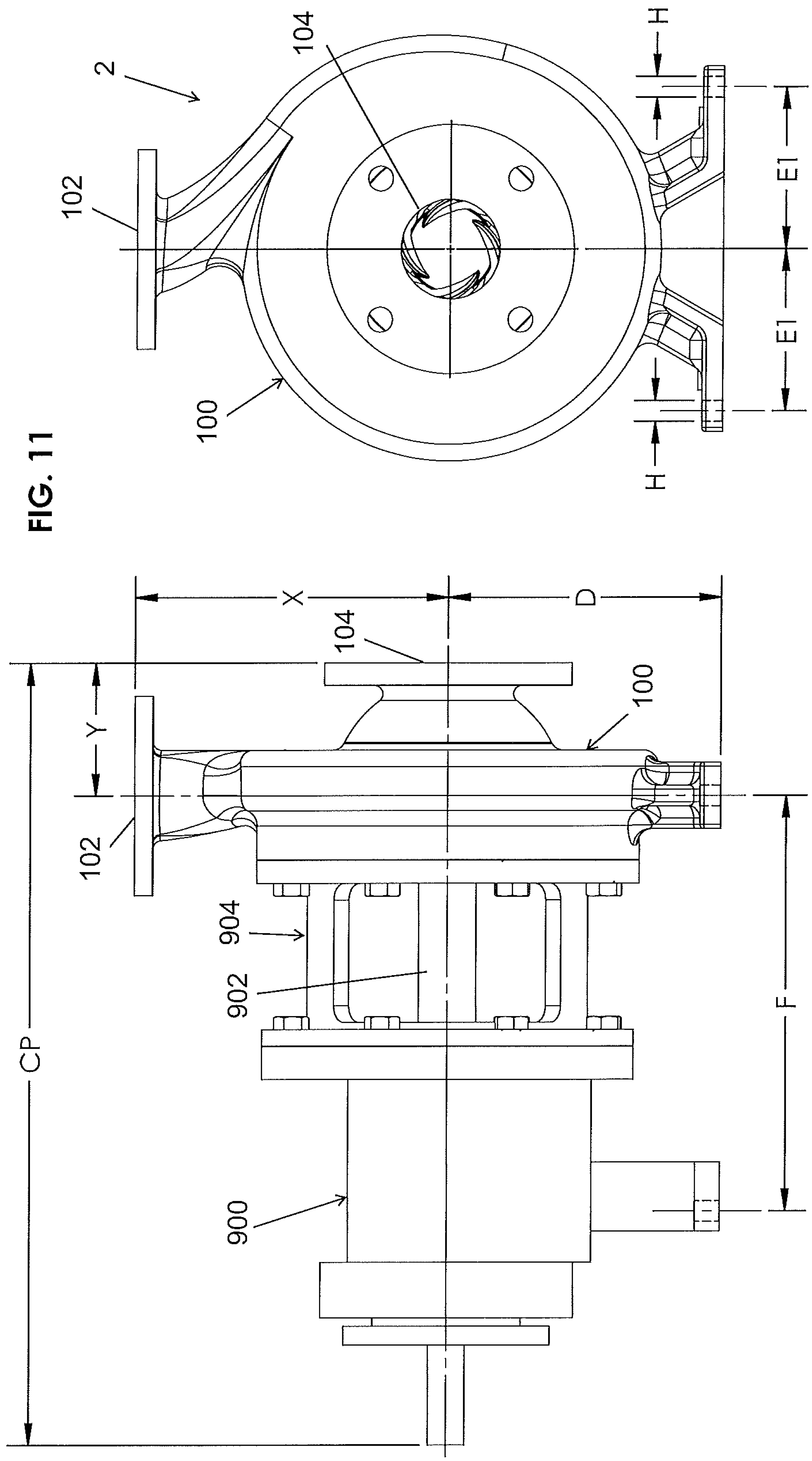


FIG. 10

FIG. 11



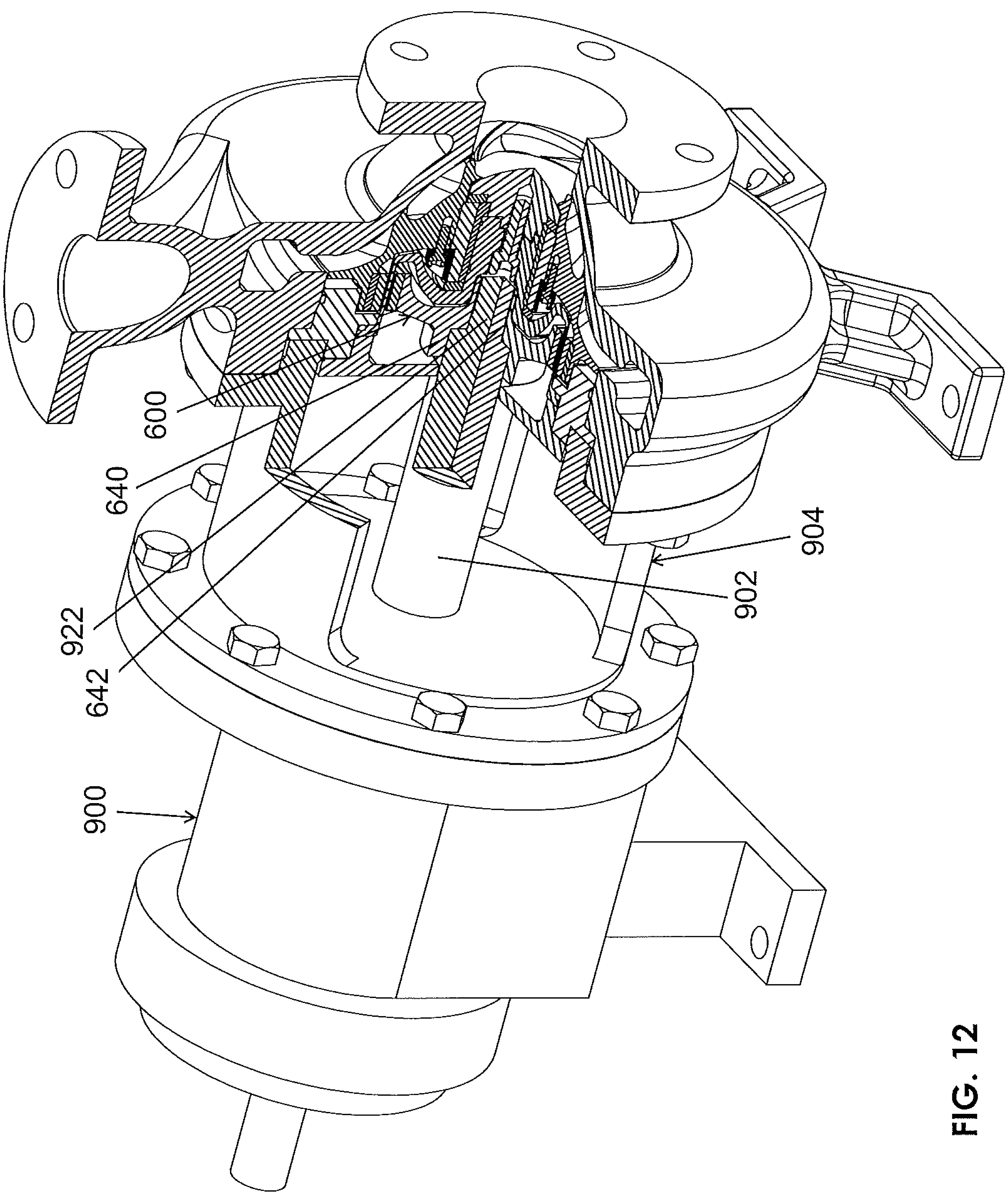


FIG. 12

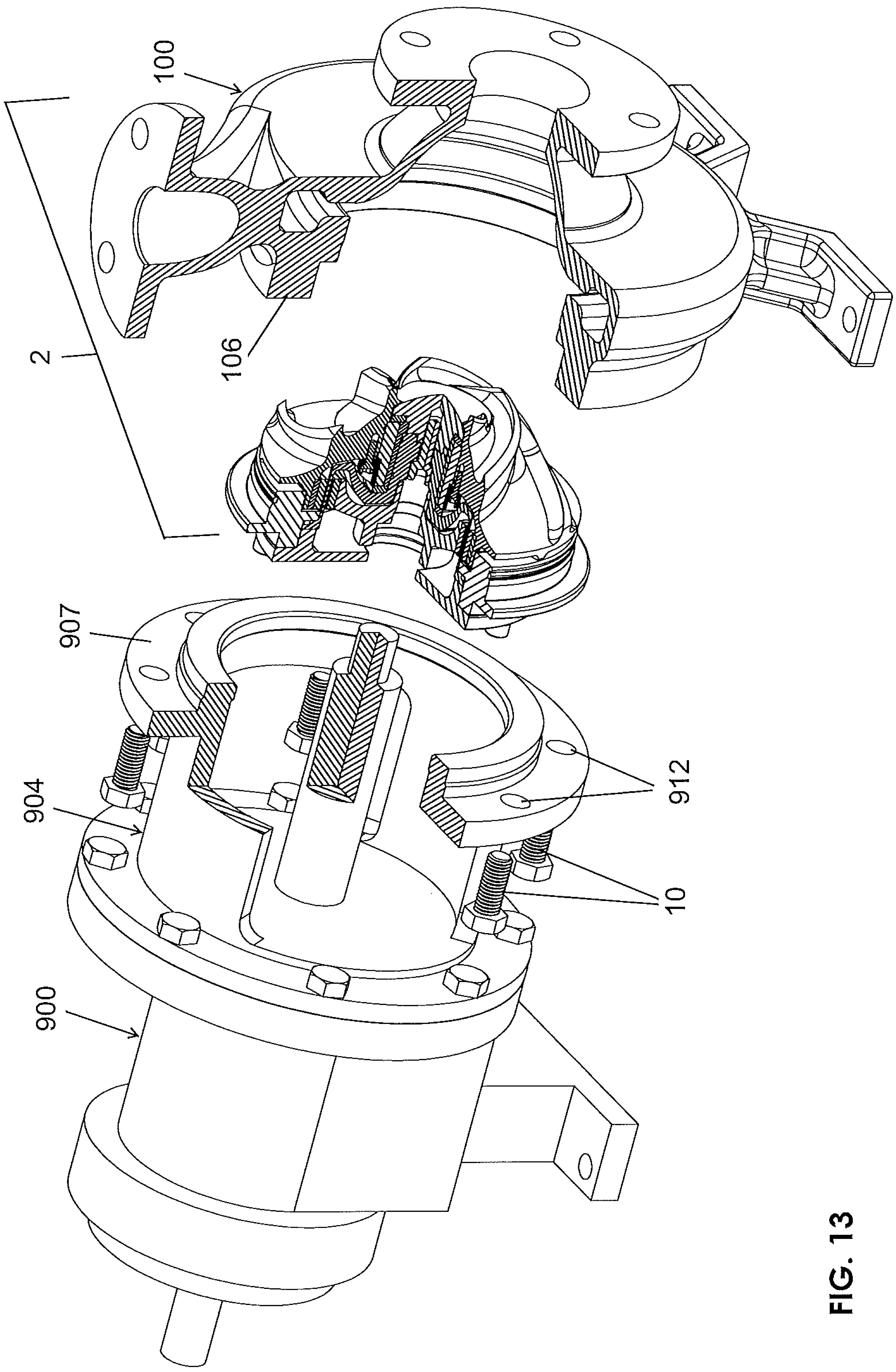
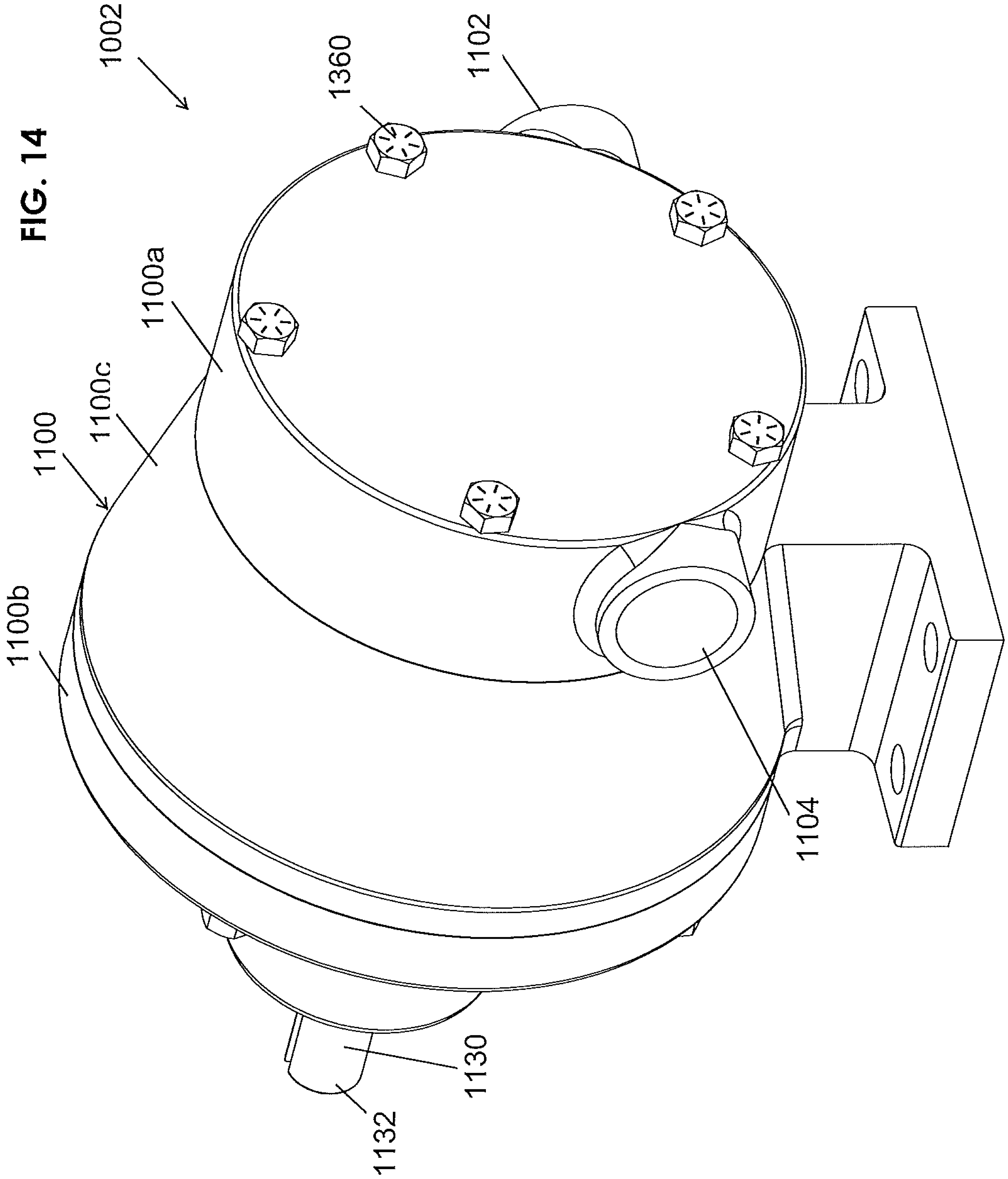
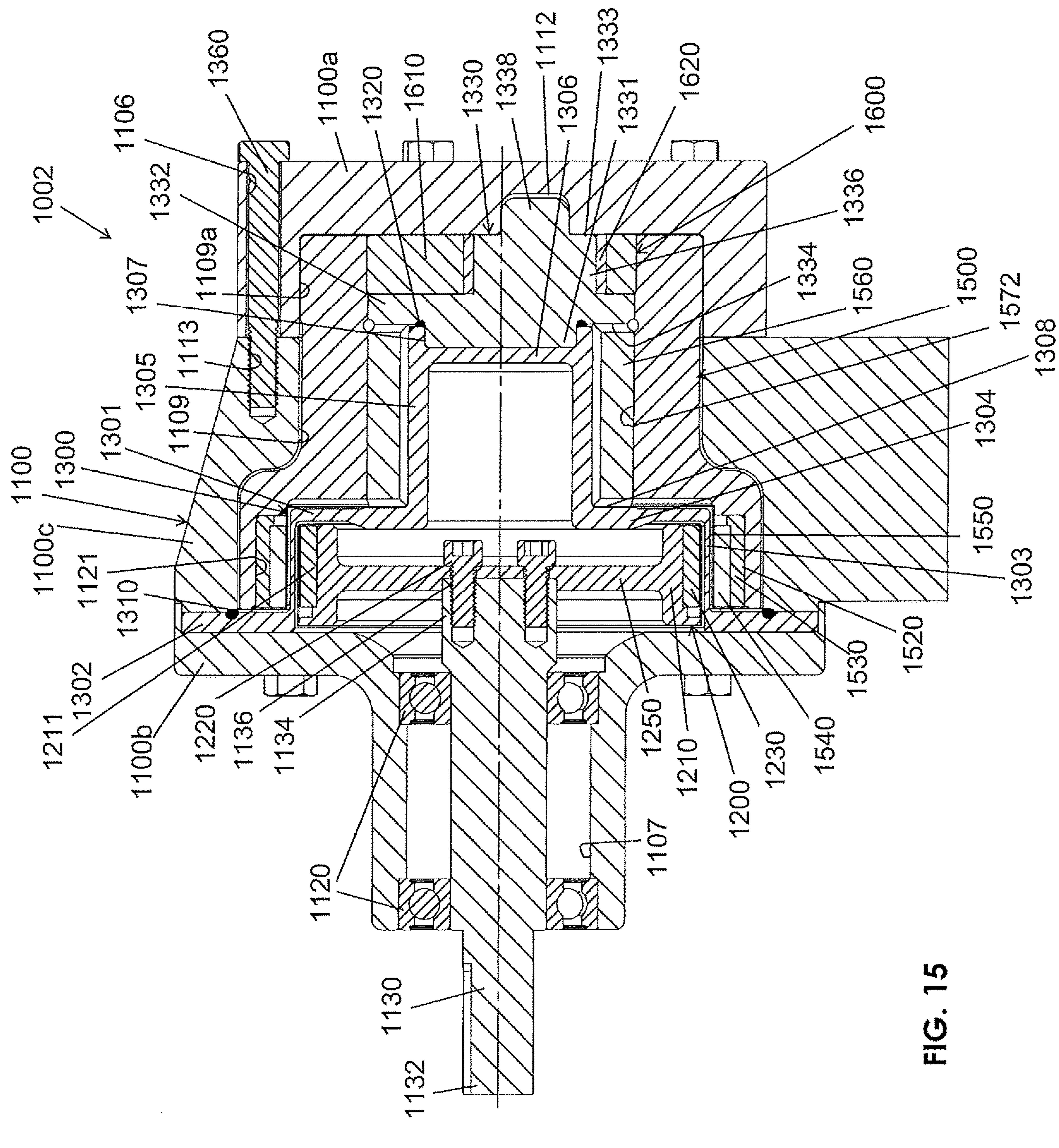


FIG. 13

FIG. 14

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1100c
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1310
1302
1211
1100b
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1136
1134
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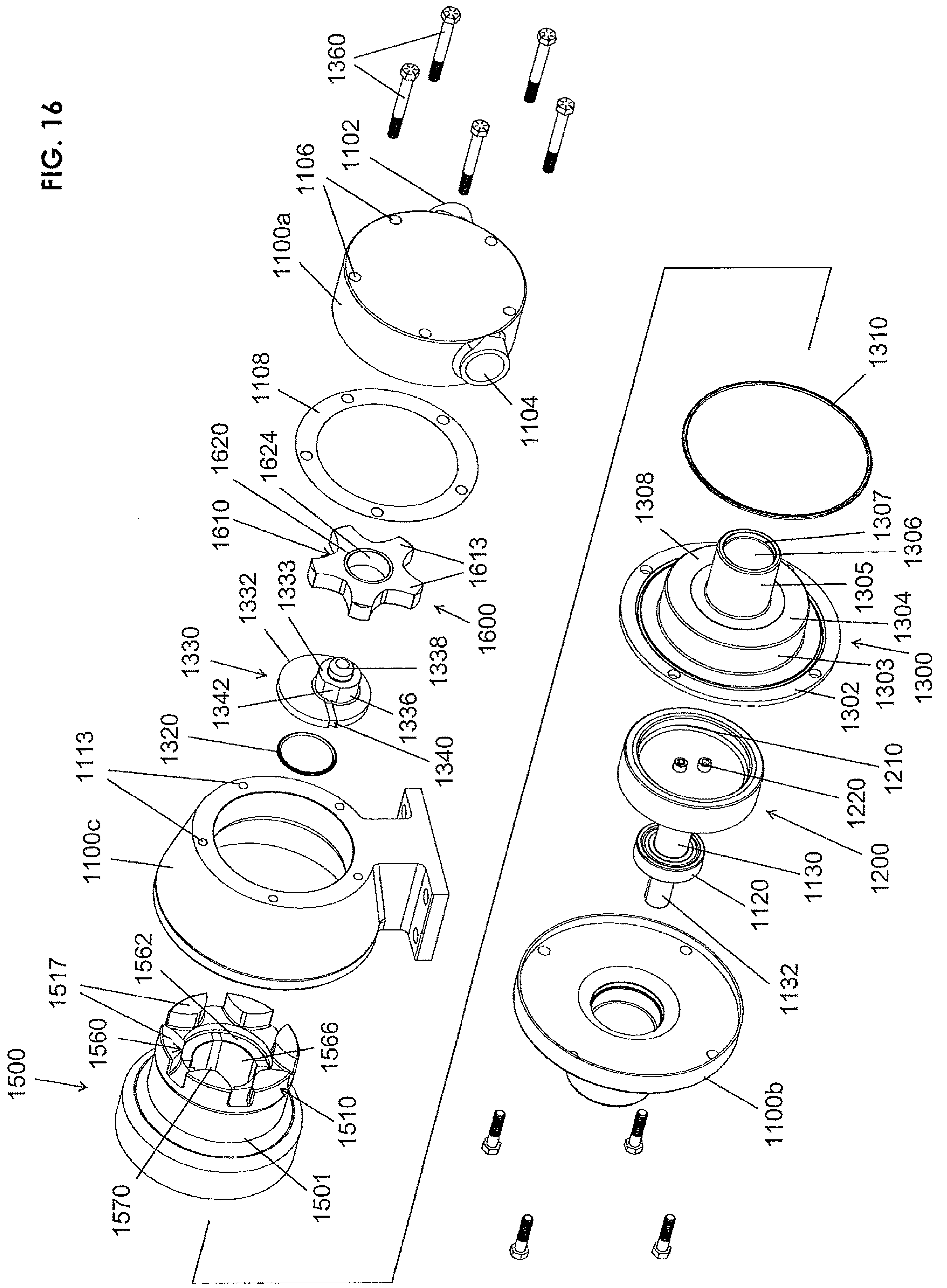
FIG. 15

FIG. 16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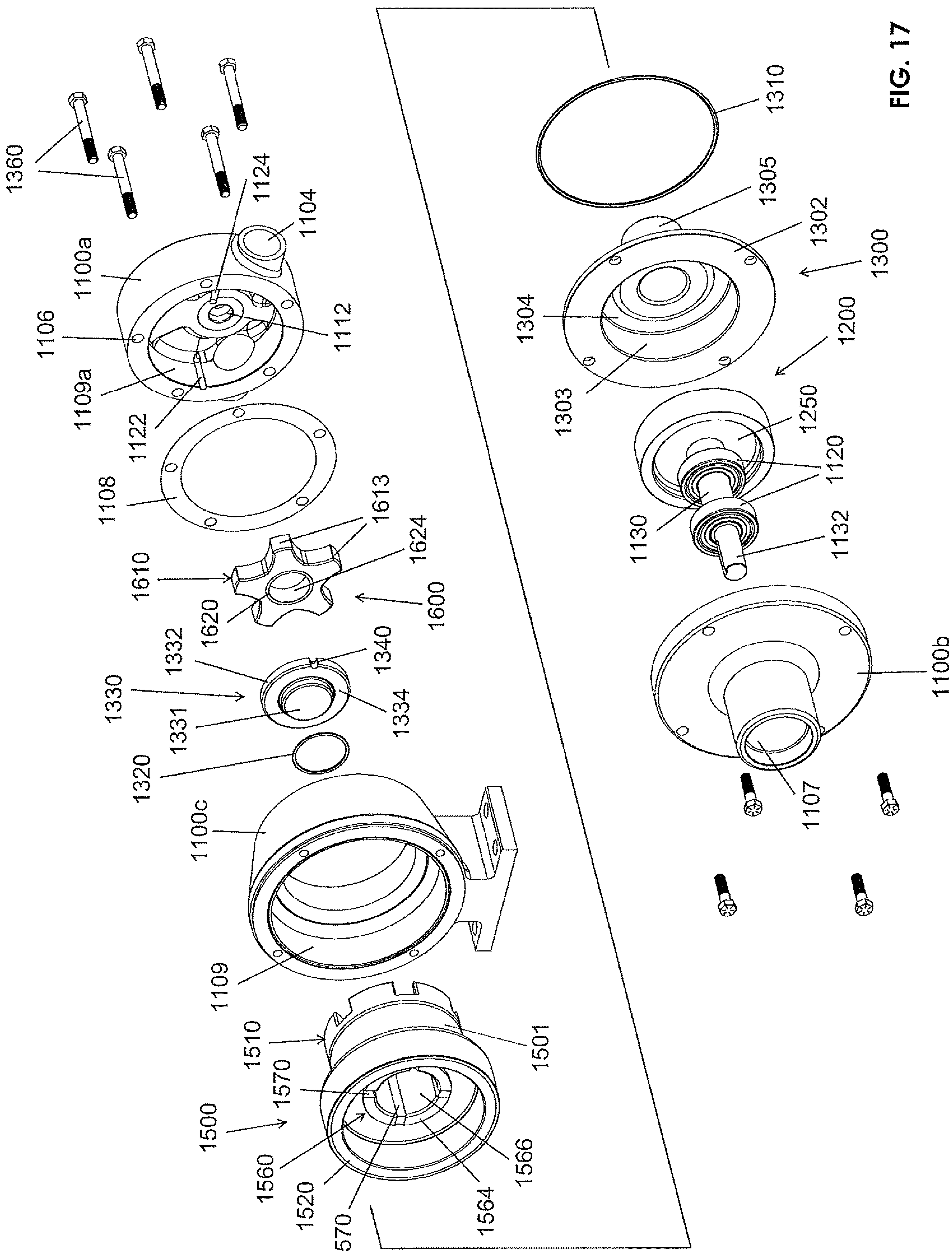
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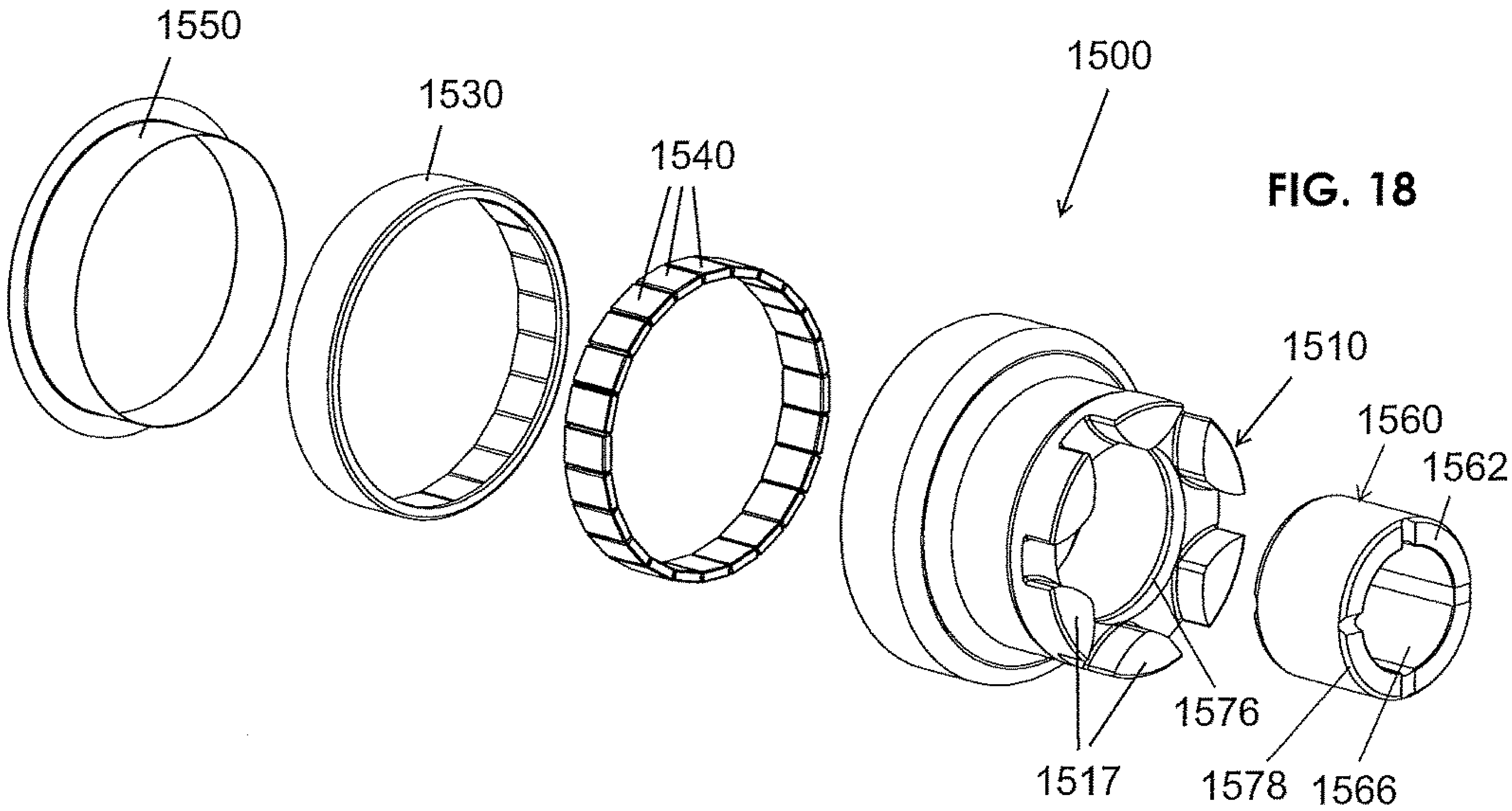
FIG. 17



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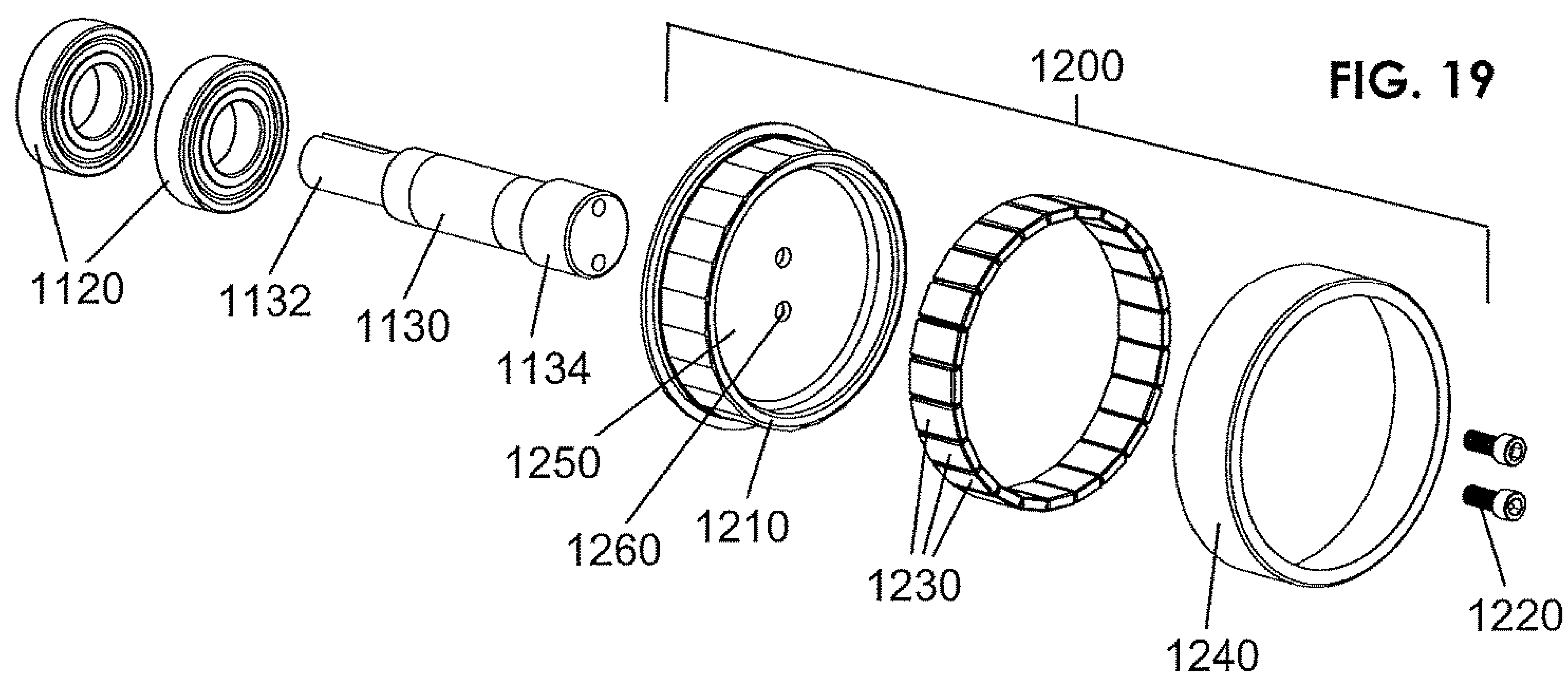


FIG. 19

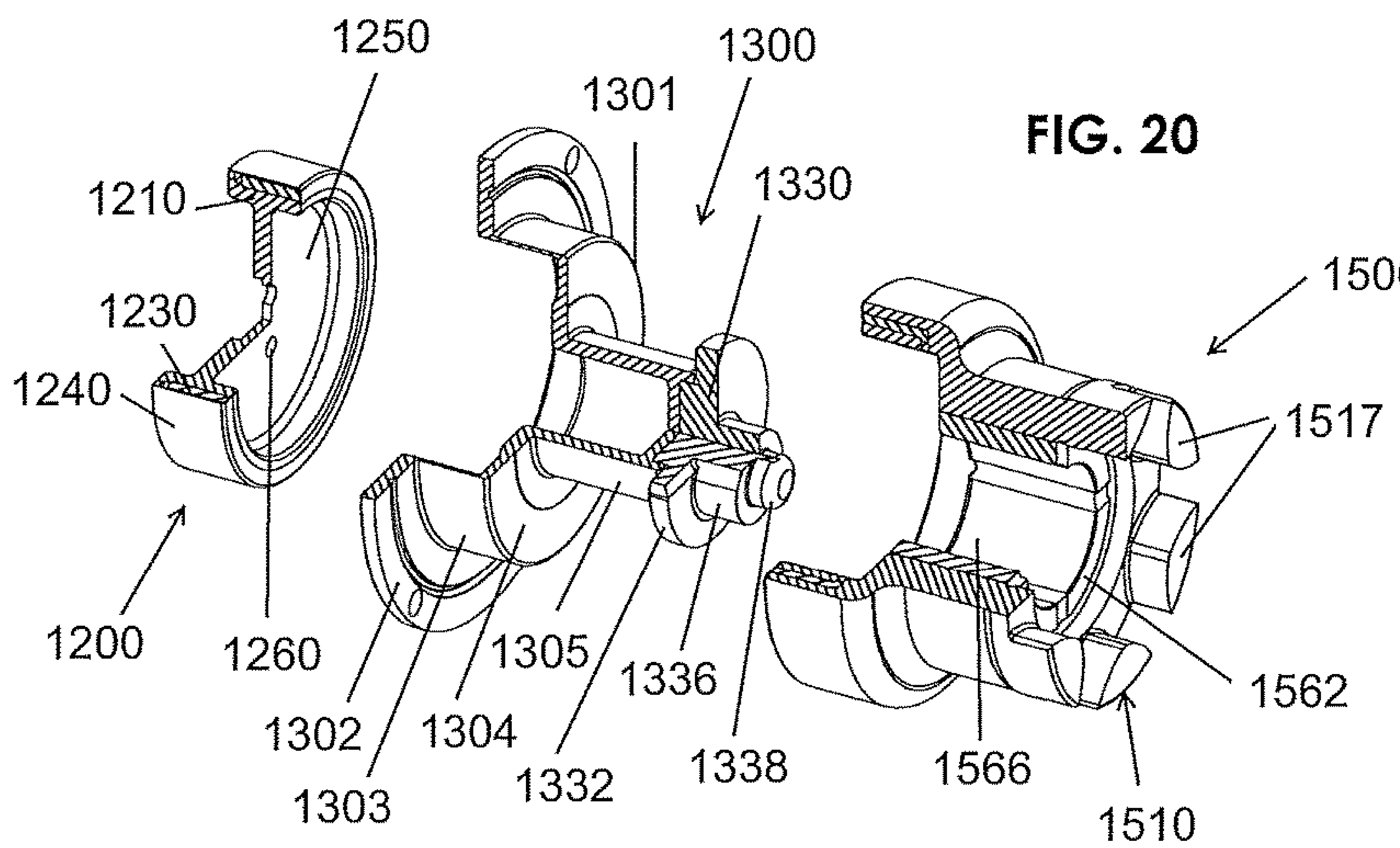
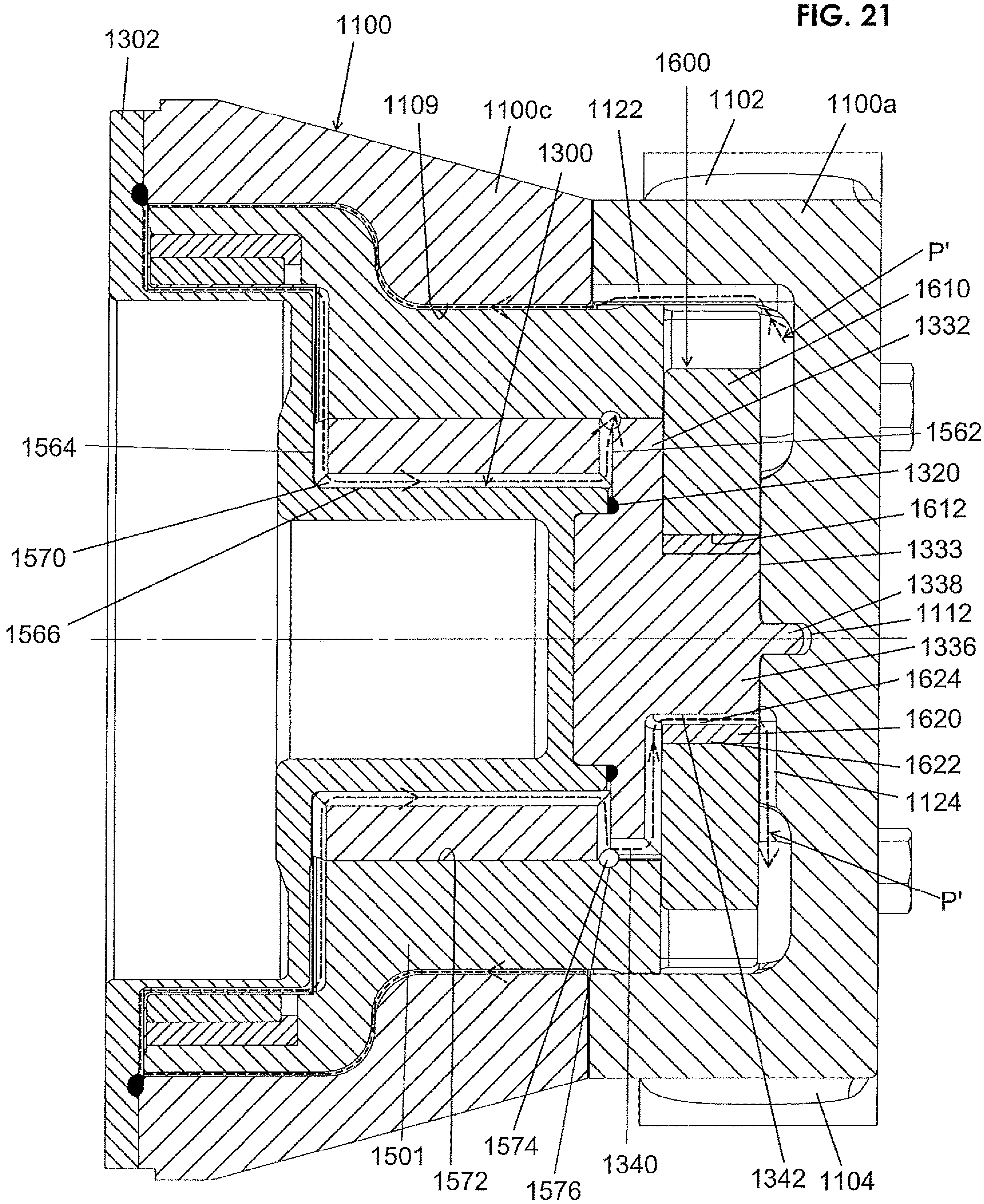


FIG. 20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1338
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1336
1624
1620
1622
1124
P'
1501
1574
1572
1576
1340
1342
1104

FIG. 21

PUMP DEVICES

BACKGROUND

Field of the Invention

The present invention generally relates to pumps, which could be in various configurations, such as in the form of rotodynamic or centrifugal pumps, or positive-displacement pumps, and which may be magnetically driven or may have dynamic seals.

Description of the Related Art

Many pumps utilize dynamic seals, which are mechanical seals between rotating parts. However, in some pumping applications, it is desirable to try to avoid potential seal leakage by not using seals in conjunction with rotating parts. Accordingly, in some instances, it is becoming more common in the pump arts to employ a magnetic drive system to eliminate the need for seals along rotating surfaces. The present disclosure addresses numerous shortcomings in prior art equipment, such as pumps, some of which utilize a magnetic coupling, while others of which may be employed with pumps having seals along rotating surfaces. The pumps also may employ rotodynamic or positive-displacement pumping principles. The following are several of the shortcomings recognized and sought to be addressed in the present disclosure.

Prior art systems for supporting a rotor assembly within a magnetically driven pump may be of different constructions but tend to provide radial and axial (thrust) bearing support for the rotor assembly that does not rely on the canister that separates the fluid pumping chamber from the drive portion of the pump. This results in a disadvantage of causing magnetically driven pumps to have greater axial length and weight, because the bearing support is located forward and/or rearward of the pumping portion of the rotor assembly. For example, bearings providing radial support and forward and rearward thrust or axial bearings that restrict forward or rearward motion typically are located forward and/or rearward of the pumping elements of a rotor assembly.

Almost all magnetically coupled pumps have a recirculation path that allows a small percentage of the pump fluid flow to recirculate from the pump outlet or discharge side, back to the inlet or suction side. This recirculation is used mostly for lubrication and cooling of bushings and for cooling of the canister, which may get hot due to electrical eddy currents generated by the magnetic coupling. Prior art recirculation paths include one or more segments where the path is essentially a hole thru a single part, such as a hole thru a single stationary part of the pump casing or thru a single piece rotating impeller. The downside of a hole thru a single part is that it is prone to causing clogging of the recirculation path.

In the chemical processing industry, the standard ASME B73.1 is a very popular specification for most centrifugal dynamically sealed pumps. In this standard and in the ISO 5199 standard, one of the main features of the specification is the establishment of a common mounting footprint, including the sizes and locations of the outlet or discharge port, the inlet port, the mounting foot and the shaft of the pump. The industry also sells magnetically coupled pumps but they utilize a different rear end mechanical drive portion or power end in comparison to the dynamically sealed pumps. There are far fewer magnetically coupled pumps, so the power ends for magnetically driven pumps tend to be more costly. Also, due to overall size and especially axial length, no magnetically coupled pumps known to the inven-

tors have been able to utilize the power end that is commonly used with the dynamically sealed pumps while meeting either of the standards for the location of the stated features involved in mounting such pumps.

When a rotor assembly of a pump includes an impeller, the pump generally is most efficient and has the best suction capability when the center starting ends of the vanes have a relatively small diameter. However, in a magnetically driven rotodynamic pump, a front nose cap that holds a front axial bearing is most beneficial if it has a relatively large outer diameter, so that the axial bearing can be large. In a typical design, a nose cap must be assembled from the front of the impeller, so the center of the forward ends of the impeller vanes must start at a diameter at least as large as the diameter of the nose cap. This requires a disadvantageous tradeoff pitting a desired small diameter for the front end of the impeller vanes against a desired large diameter of a front axial bearing.

As noted above, it is common for pumps to have separate radial and axial bushings or bearings. This tends to add undesirable complexity and length to a pump.

The above are some of the shortcomings of prior art pumps that are sought to be addressed by the teachings and examples provided in the present disclosure.

SUMMARY

In a first aspect, the present disclosure provides a magnetically driven pump having a compact advantageous design that overcomes the above discussed disadvantages associated with having radial and axial bearing surfaces well forward or rearward of the pumping area of a rotor assembly. The disclosure provides a magnetically driven pump that includes a casing, a rotor assembly, an inner magnet assembly and a canister assembly. The casing has a front portion, a rear portion, a discharge port and an inlet port. The rotor assembly includes a rear cylindrical opening having an inner wall surface and having a plurality of magnet segments connected to the inner wall surface, a front cylindrical opening having an inner wall surface that provides a radial bearing surface, and a first axial bearing surface. The canister assembly includes a cylindrical portion disposed within a radial gap between magnet segments of the inner magnet assembly and magnet segments of the rotor assembly, and a front portion extending from the cylindrical portion and having a radial bearing surface and a first axial bearing surface. In this design, the radial bearing surface of the rotor assembly and the radial bearing surface of the canister assembly front portion restrict radial motion of the rotor assembly, and the first axial bearing surface of the rotor assembly and the first axial bearing surface of the canister assembly front portion restrict forward motion of the rotor assembly.

In a second aspect, the present disclosure addresses the disadvantageous structures of prior art magnetically driven pumps having a recirculation path through a single part or through stationary segment. The disclosure provides a magnetically driven pump that includes a stationary casing, a rotatable rotor assembly, a rotatable drive magnet assembly, a stationary canister assembly, and a recirculation path. The stationary casing has a front portion, a rear portion, a discharge port and an inlet port. The rotatable rotor assembly includes a rotor, at least one radial bearing surface, at least one axial bearing surface and a plurality of magnet segments. The rotatable drive magnet assembly includes a plurality of magnet segments in axial alignment with the magnet segments of the rotor assembly. The stationary canister assembly includes a cylindrical portion disposed within a radial gap between the magnet segments of the rotor assembly and the magnet segments of the drive magnet assembly. The recirculation path extends from the casing discharge port, across the at least one radial bearing surface of the rotor assembly, across the at least one axial bearing surface of the rotor assembly, across the cylindrical portion of the canister assembly, and to the casing inlet port, wherein when the rotor assembly rotates within the casing and relative to the canister assembly, all portions of the recirculation path include at least one stationary surface of the casing or canister assembly that is opposed to at least one surface of the rotor assembly.

In a third aspect, the present disclosure also addresses the lack of magnetically driven pumps able to meet the industry standards ASME B73.1 and/or ISO 5199 for mounting locations of key features and able to utilize the rear end mechanical drive portion commonly used with dynamically sealed pumps that meet the standard. The disclosure provides a magnetically driven rotodynamic pump that includes a stationary casing, an inner magnet assembly, and an impeller assembly. The stationary casing includes a discharge port, an inlet port, a mounting foot and a rear mounting flange. The inner magnet assembly has an inner ring and a plurality of magnet segment. The casing, inner magnet assembly and impeller assembly are configured and dimensioned to be assembled to a power end and adapter of a commercially available non-magnetically driven rotodynamic pump having a dynamic seal that is designed in accordance with dimensions specified in a pump industry standard, such that when assembled, the sizes and locations of the casing discharge port, the casing inlet port, the casing mounting foot, and the power end and adapter all meet the dimensions specified in the standard. The unique, axially compact design of a pump of the present disclosure is capable of utilizing the rear end mechanical drive components or power end normally in place for such centrifugal dynamically sealed pumps. Thus, the pump may be installed without needing to remove the power end that is connected to the electric drive motor, and therefore, without disturbing the electric motor and its mounting and electrical connections, and without disturbing the shaft alignment between the electric motor and the power end. Also, the new pump advantageously may be connected to existing power end and adaptor structures. This can be particularly beneficial to manufacturers that already make the power end and adapter components for the centrifugal dynamically sealed pumps. Moreover, it permits utilization of the less expensive power ends normally used with dynamically sealed pumps, and provides an opportunity for field retrofits that can be achieved by leaving in place the existing power end and only changing out the pump, while also gaining the advantages of a magnetically driven pump.

In a fourth aspect, the present disclosure addresses the previously noted issue that typical magnetically driven rotodynamic pumps having a front axial bearing at a nose cap must balance the benefit of having a small diameter at the center starting portion of the impeller vanes against the benefit of having a large diameter canister nose cap for the front axial bearing. The disclosure provides a magnetically driven rotodynamic pump having a stationary casing, a stationary canister assembly, and a rotatable rotor assembly. The stationary casing has a front portion, a rear portion, a discharge port and an inlet port. The stationary canister assembly is connected to the stationary casing. The stationary canister assembly further includes a canister and a stationary nose cap is connected to the canister and has an outer diameter, a rear axial bearing surface and a front surface. The rotatable rotor assembly includes an impeller having a plurality of front vanes, wherein a portion of the impeller front vanes extend forward of the nose cap front surface and inward to an inner diameter that is smaller than the outer diameter of the nose cap. Thus, the design includes the benefits of both a smaller diameter at the center starting portion of the impeller vanes and a large diameter canister nose cap having a front axial bearing. In this design, the stationary front surface of the nose cap is positioned where there would otherwise be an impeller base surface and the forward extending portions of the impeller vanes extend forward of the surface of the base of the impeller. This results in an advantageous relatively small diameter of the center starting ends of the impeller vanes combined with an advantageous relatively large outer diameter of the axial bearing at the nose cap of the canister assembly.

In a fifth aspect, the present disclosure provides a pump that includes a stationary casing having a front portion, a rear portion, a discharge port and an inlet port, and further includes a rotor assembly having a bushing wherein the bushing is of single piece construction and includes a radial bearing surface that restricts radial motion of the rotor assembly, a front axial bearing surface that restricts forward motion of the rotor assembly, and a rear axial bearing surface that restricts rearward motion of the rotor assembly. This design is believed to provide the first instance of a pump having a bushing for a rotor assembly that is of single piece construction while providing radial and front and rear axial bearing surfaces. This provides a particularly compact rotor assembly design.

In an sixth aspect, the present disclosure provides a pump that includes a stationary casing having a front portion, a rear portion, a discharge port and an inlet port, and further includes a rotor assembly having a rotor that includes a central opening extending axially through the rotor and having a step proximate one end of the central opening, a rotor ring, and a bushing, wherein the bushing fits inside the rotor central opening and is held in place between the rotor ring and the step in the central opening of the rotor. This design provides a uniquely compact and efficient bushing design and construction for a rotor assembly wherein a bushing extends through a portion of and is held within the rotor assembly by a fastening means at one end of the rotor assembly. This also enables the use of advantageous longer bearing surfaces.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and provided for purposes of explanation only, and are not restrictive of the subject matter claimed. Further features and objects of the present disclosure will become more fully apparent in the following description of the preferred embodiments and from the appended claims. Indeed, it is contemplated that certain aspects of the present disclosure pertain to pumps that may be dynamically sealed and/or magnetically driven and considered to be sealless, while certain aspects also pertain to rotodynamic pumps and/or positive-displacement pumps. It also will be appreciated that, if magnetically driven, some aspects may be applied to pumps having an inner magnet drive assembly and/or an outer magnet drive assembly.

BRIEF DESCRIPTION OF THE DRAWINGS

In describing the preferred embodiments, references are made to the accompanying drawing figures wherein like parts have like reference numerals, and wherein:

FIG. **1** provides a side view and a front view of a first example pump connected to a motor using an adapter and shaft extension in a close-coupled fashion.

FIG. **2** provides a quarter-sectioned perspective view of the first example pump of FIG. **1**.

FIG. **3** provides an enlarged closer perspective view of the quarter-sectioned area of FIG. **2**.

FIG. **4** provides a perspective view of the first example pump of FIG. **1** with a sectioned front portion of the casing.

FIG. **5** provides a front view of the first example pump of FIG. **1** with a sectioned front portion of the casing.

FIGS. **6***a* and **6***b* provide quarter-sectioned rear and front perspective views of the rotor assembly of the first example pump of FIG. **1**.

FIG. **7** provides a quarter-sectioned perspective partially exploded view of the inner portion of the first example pump of FIG. **1**.

FIG. **8** provides a partially quarter-sectioned perspective partially exploded view of the rotor assembly of the first example pump of FIG. **1**.

FIG. **9** provides a perspective exploded view of the center portion of the first example pump of FIG. **1**.

FIG. **10** provides a portion of a quarter-sectioned plan view of the first example pump of FIG. **1** showing a recirculation path and without the power end drive components.

FIG. **11** provides a side view and a front view of a second example pump connected to a power end that is suitable for another pump meeting ASME B73.1 or ISO 5199 dimensional standards.

FIG. **12** provides a quarter-sectioned perspective view of the second example pump of FIG. **11**.

FIG. **13** provides a quarter-sectioned perspective partially exploded view of the second example pump of FIG. **11**.

FIG. **14** provides a front perspective view of a third example pump.

FIG. **15** provides a cross-sectioned view of the third example pump of FIG. **14**.

FIG. **16** provides a front perspective partially exploded view of the third example pump of FIG. **14**.

FIG. **17** provides a rear perspective partially exploded view of the third example pump of FIG. **14**.

FIG. **18** provides a front perspective exploded view of the rotor assembly of the third example pump of FIG. **14**.

FIG. **19** provides a front perspective exploded view of the drive magnet assembly of the third example pump of FIG. **14**.

FIG. **20** provides a quarter-sectioned perspective partially exploded view of the drive magnet assembly, canister and rotor assembly of the third example pump of FIG. **14**.

FIG. **21** provides a portion of a quarter-sectioned plan view of the pump of FIG. **14** showing a recirculation path and without the power end drive components.

It should be understood that the drawings are not to scale. While some mechanical details of the example pumps, including details of fastening means and other plan and section views of the particular components, have not been shown, such details are considered to be within the comprehension of those skilled in the art in light of the present disclosure. It also should be understood that the present disclosure and claims are not limited to the preferred embodiments illustrated.

DETAILED DESCRIPTION

Referring generally to FIGS. **1-21**, it will be appreciated that pumps devices of the present disclosure generally may be embodied within numerous configurations. Indeed, the teachings within this disclosure may pertain to dynamically sealed pumps, whether of the rotodynamic or positive-displacement types, and/or to magnetically driven or sealless pumps, whether of the rotodynamic or positive-displacement types. If of the magnetically driven type, the pumps may be of the inner magnet drive and/or outer magnet drive types.

Referring to a preferred first example embodiment, in FIGS. **1-10**, and particularly to FIGS. **1** and **2**, an example pump **2** is shown connected to a motor adapter **4** that, in turn, is connected to a standard C-face electric motor **6**. The configuration of pump **2** happens to be a magnetically driven rotodynamic pump. More particularly, a first flange **5** of the adapter **4** is connected to the motor **6** by use of a plurality of fasteners **8**, such as threaded screws or other suitable means of connection. In this first example, the motor **6** includes a motor shaft **22** to which is connected a shaft extension **620**, and it will be appreciated that in combination with the adapter **4**, these components provide the rear end mechanical drive portion or power end that is connected to the pump **2**.

The pump **2** includes a casing **100** that is intended to be mounted in place, so as to be stationary. The casing **100** includes a front portion **100***a* and a rear portion **100***b*. The casing **100** also has an outlet or discharge port **102** and an inlet port **104**. In this first example, the discharge port **102** is radially facing, while the inlet port **104** is axially facing, although alternative configurations may be utilized. The casing **100** includes a rear face **106** that is connected to a second flange **7** of the adapter **4** by use of a plurality of fasteners **10** that pass through apertures in the second flange **7** and engage threaded holes in the casing rear face **106**. The casing **100** may be constructed of rigid materials, such as steel, stainless steel, cast iron or other metallic materials, or structural plastics or the like.

As may be seen in FIGS. **2** and **9**, the pump **2** also includes a backplate **200** that has an outer flange **202**. The backplate outer flange **202** is clamped between the casing **100** and the adapter **4** when connecting the pump **2** to the adapter **4** by installing the fasteners **10**. Sealing is provided between the casing **100** and the backplate **200** by an O-ring **13**, although other methods of sealing may be employed, such as use of a gasket, liquid sealant or the like. The pump **2** also includes a rear cover **300** that has an outer flange **302**. The rear cover **300** is connected to the backplate **200** by use of a plurality of fasteners **14**, such as threaded screws that pass through apertures **304** in the rear cover **300** and engage threaded holes in a rear face of the backplate **200**.

The pump **2** also includes a canister assembly **400** that includes a canister **400***a* that has an outer flange **402**. The canister outer flange **402** is clamped between the backplate **200** and the rear cover **300** when connecting the rear cover **300** to the backplate **200** by installing the fasteners **14**. Sealing is provided between backplate **200** and the canister assembly **400** by an O-ring **16**, although other methods of sealing may be employed, such as use of a gasket, liquid sealant or the like. The canister assembly **400** also includes a front portion **404** that includes a front face **406** having a front cavity **408** and an aperture **410** that passes through the front portion **404**. The canister assembly **400** may be constructed of rigid materials. It will be appreciated that common materials may be used, such as stainless steel, or low conductivity metals, such as alloy C-22 or alloy C-276, and it could be advantageous to use materials having very low electrical conductivity, such as silicon carbide, ceramic, polymers or the like.

In addition, the canister assembly **400** includes a nose cap **500**, which has a threaded hole **502**, a rear face **504** and a rear extended portion **506**. The nose cap **500** is attached to the canister assembly front portion **404** by a fastener **18**, such as a threaded screw that passes through the aperture **410** in the front portion **404** and engages the threaded hole **502** in the rear of the nose cap **500**. In this first example embodiment, there is just one fastener **18** securing the nose cap **500**, but it will be appreciated by one of skill in the art that a plurality of fasteners or other suitable fastening means may be employed in assembling the components of the canister assembly **400**. Also, in this first example pump **2**, the front portion **404** and nose cap **500** of the canister assembly **400** are spaced from the front portion **100***a* of the casing **100**, such that they do not receive support from the front portion **100***a*. The nose cap **500** may be constructed of rigid materials, such as steel, stainless steel, cast iron or other metallic materials, or structural plastics or the like.

The shape of the front cavity **408** is not cylindrical, and it corresponds to a non-cylindrical shape of the nose cap extended portion **506**, so as to prevent relative rotation between the nose cap **500** and canister **400***a* when connected by the fastener **18**, and to ensure that the canister assembly will remain stationary. Throughout this disclosure, it will be appreciated that alternative ways of preventing relative rotation between components may be used, such as by use of one or more fasteners, welding or other suitable alternatives. Sealing between the canister **400***a* and the nose cap **500** is provided by an O-ring **20**, although other methods of sealing may be employed, such as use of a gasket, liquid sealant or the like.

The pump **2** further includes a drive magnet assembly, such as an inner magnet assembly **600** that includes an inner ring **640** which may be connected directly to a motor shaft, or in this example, to the shaft extension **620**. The inner ring **640** has a central threaded aperture **642** and the shaft extension **620** has a mating externally threaded front portion **622**, which is used to connect the inner ring **640** to the shaft extension **620**. In this first example embodiment, the shaft extension **620** and inner ring **640** are separate pieces, but it will be appreciated that they could be combined, so as to be a single piece, or a different method of connection may be used. The inner ring **640** may be constructed of rigid materials, but is preferably constructed of a material with high magnetic permeability, such as iron, carbon steel or the like.

The shaft extension **620** of this example includes an inner opening **624** that slidably receives a shaft **22** of the motor **6**. The shaft extension **620** also includes a keyway **626** and one or more threaded apertures **628**. A key **24** is positioned in the shaft extension keyway **626** and engages with a keyway **26** of the motor shaft **22**, to provide a positive rotational connection between the shaft extension **620** and the motor shaft **22**. One or more setscrews **28** are positioned in the shaft extension threaded apertures **628** and are tightened against the keyway **26** of the motor shaft **22**, to provide a positive axial connection between the shaft extension **620** and the motor shaft **22**.

The inner ring **640** of the drive magnet assembly, such as inner magnet assembly **600** includes an outer surface **644** to which are connected twenty-four magnet segments **646**, although it will be appreciated that one may have an embodiment with a different quantity of magnet segments. The magnet segments **646** are radially charged and are positioned with alternating polarity. The magnet segments **646** are rigidly connected to the inner ring **640** using an adhesive, although alternative suitable means of connection may be used, such as use of fasteners or the like. Although not required, this example embodiment includes an inner magnet sleeve **648** having a thin cylindrical portion **650** that closely fits over the outer surfaces of the magnet segments **646**.

The pump **2** also includes a rotatable rotor assembly, such as a rotatable impeller assembly **700** that includes a rotor, such as an impeller **702**. The impeller **702** includes a rear opening **704**, which receives a driven magnet assembly, such as an outer magnet assembly **705**. The outer magnet assembly **705** includes an outer ring **706** having an inner wall surface **708** to which are connected twenty-four magnet segments **710**, which corresponds to the number connected to the inner ring **640**, although it will be appreciated that one may have an embodiment with a greater or lesser quantity of magnet segments. The magnet segments **710** are radially charged and are positioned with alternating polarity. The magnet segments **710** are rigidly connected to the outer ring **706** using an adhesive, although alternative suitable means of connection may be used, such as use of fasteners or the like. An impeller magnet sleeve **712** is included having a thin cylindrical portion **714** that closely fits along the inner surfaces of the magnet segments **710**. The impeller magnet sleeve **712** also includes a rear flange **718**. The impeller magnet sleeve **712** is sealingly connected to the impeller **702** by continuous weld joints located at an outer end **720** of the rear flange **718** and at a front end **722** of the cylindrical portion **714**. It will be appreciated by one of skill in the art that other methods of connection may be used, such as liquid adhesive, gaskets, O-rings or the like. The rotor or impeller **702** may be constructed of rigid materials, such as steel, stainless steel, cast iron or other metallic materials, or structural plastics or the like. The outer ring **706** may be constructed of rigid materials, but preferably is constructed of a material with high magnetic permeability, such as iron, carbon steel or the like.

Referring to FIGS. **6***a* and **6***b*, the rotatable rotor assembly or impeller assembly **700** includes a rotor or impeller **702** having a central opening **724** that includes one or more grooves **726**. A bushing **800** is received in the central opening **724** of the rotor or impeller **702**, and one or more O-rings **30** are positioned between an outer surface **802** of the bushing **800** and the grooves **726** in the central opening **724** of the impeller **702**. The bushing **800** is held in a forward direction against a step **727** in the central opening **724** proximate an end of the central opening **724** of the impeller **702**, where there is a transition from a first inner surface **727***a* to a second inner surface **727***b* having a smaller diameter. The bushing outer surface **802** is slightly smaller than the rotor or impeller central opening **724**, and the O-rings **30** are not intended to provide sealing between the two surfaces. Rather, in the event that the operating temperature may vary, and the bushing **800** and the impeller **702** may be made of materials with different rates of thermal expansion, then the size or extent of the clearance between the bushing **800** and impeller **702** will change and the compression of the O-rings **30** of this example embodiment will accommodate this clearance change and will maintain a concentric relationship between the bushing **800** and the impeller **702**.

The rotor or impeller **702** further includes a rear surface **728** that includes one or more threaded holes **730**. An impeller rear cap, such as rotor ring **732** having a central opening **736** is connected to the impeller rear surface **728** by at least one fastener **32**, such as by a plurality of screws that pass through apertures **734** in the rotor ring **732** and engage the threaded holes **730** in the impeller **702**. The bushing **800** includes a rear portion **804** with a shape that is not cylindrical, and it corresponds to a non-cylindrical shape of the central opening **736** in the rotor ring **732** to prevent relative rotation between the bushing **800**, rotor ring **732** and impeller **702**, although as previously noted, alternative ways of preventing relative rotation may be utilized. Thus, the bushing **800** fits inside the central opening **736** extending axially through the rotor or impeller **702** and is held in place between the rotor ring **732** and the step **727** in the central opening **736** of the impeller **702**.

As will be further described and more fully appreciated, within this first example pump **2**, the bushing **800** provides the rotatable rotor assembly or impeller assembly **700** a radial bearing surface, a first or front axial bearing surface, and a second or rear axial bearing surface. In this example, these bearing surfaces engage respective bearing surfaces of the canister assembly **400**, which as will be described further herein more particularly include a radial bearing surface provided by a bearing sleeve **806**, a first or front axial bearing surface provided by a front thrust washer **818**, and a second or rear axial bearing surface provided by a rear thrust washer **814**.

Thus, the canister assembly **400** of the first example pump **2** also includes a stationary bearing sleeve **806** that has a cylindrical shape. The front portion **404** of the canister **400*a*** includes an outer surface **412** having at least one groove **414**. The bearing sleeve **806** is positioned over the outer surface **412** of the front portion **404**, and at least one O-ring **34** is positioned between the outer surface groove **414** of the front portion **404** and an inner surface **808** of the bearing sleeve **806**. In this example embodiment, two O-rings **34** are received in two grooves **414**. The outer surface **412** of the front portion **404** of the canister **400*a*** is slightly smaller than the inner surface **808** of the bearing sleeve **806**. In the event that the operating temperature may vary and the canister **400*a*** and the bearing sleeve **806** may be made of materials with different rates of thermal expansion, then the size or extent of the clearance between the canister **400*a*** and the bearing sleeve **806** will change. The O-rings **34** are not intended to seal, but the compression of the O-rings **34** will accommodate this clearance change and will maintain a concentric relationship between the canister **400*a*** and the bearing sleeve **806**. In this manner, the bearing sleeve **806** provides the canister assembly **400** with a radial bearing surface for rotational engagement with the bushing **800** of the rotor assembly **700**.

The outer surface **810** of the stationary bearing sleeve **806** provides the canister assembly **400** a radial bearing surface at the front portion **404** of the canister **400*a***, which is slightly smaller than an inner wall surface **812** of the bushing **800**. The inner wall surface **812** serves as a central cylindrical opening for the rotor assembly, such as impeller assembly **700**, and provides a radial bearing surface for the impeller assembly **700**. Thus, the rotatable rotor assembly, such as impeller assembly **700**, has a bushing **800** having a radial bearing surface **812** that rotates in engagement with and is supported by the outer surface **810** of the stationary bearing sleeve **806** of the canister assembly **400**.

The canister assembly **400** of pump **2** of this first example embodiment also includes a stationary rear thrust washer **814** having a central opening **816** with a shape that is not cylindrical. The canister **400*a*** includes a center portion **416** having a non-cylindrical shape that corresponds to the shape of the central opening **816** of the rear thrust washer **814**, to prevent relative rotation between the canister **400** and rear thrust washer **814**, although suitable alternative ways of preventing relative rotation may be utilized. The canister **400*a*** includes a center wall **418** that has a front surface **420**. The rear thrust washer **814** is positioned over the canister center portion **416** and against the front surface **420** of the canister center wall **418**.

The canister assembly **400** of pump **2** further includes a stationary front thrust washer **818** with a central opening **820** having a shape that is not cylindrical. The nose cap **500** includes a center portion **508** having a non-cylindrical shape that corresponds to the shape of the central opening **820** of the front thrust washer **818** to prevent relative rotation between the nose cap **500** and front thrust washer **818**, although suitable alternative ways of preventing relative rotation between the components of the canister assembly **400** may be utilized. The nose cap **500** has a front surface **509** that includes a front flange **510**. The front flange **510** also has a rear surface **512**. The front thrust washer **818** is positioned over the center portion **508** of the nose cap **500** and against the rear surface **512** of the front flange **510** of the nose cap **500**.

It will be appreciated that while the bearing sleeve **806** provides the canister assembly **400** a radial bearing surface **810**, the front thrust washer **818** has a rear surface **828** that provides the canister assembly **400** a first or front axial bearing surface and the rear thrust washer **814** has a front surface **826** that provides the canister assembly **400** a second or rear axial bearing surface, these bearing surfaces alternatively could be integral with the front portion **404** of the canister assembly **400**.

The bushing **800** of the rotor assembly or impeller assembly **700** has a length that is slightly shorter than the length of the bearing sleeve **806** of the canister assembly **400**. The bearing sleeve **806** is positioned between the rear thrust washer **814** and the front thrust washer **818** of the canister assembly **400**, creating a gap equal to the length of the bearing sleeve **806**. The impeller assembly **700** is positioned such that the bushing **800** is in the gap between the rear thrust washer **814** and the front thrust washer **818**. The bushing **800** also has a front surface **822** and a rear surface **824**. The front surface **822** provides the impeller assembly **700** a first or front axial bearing surface. Similarly, the rear surface **824** provides the impeller assembly **700** a second or rear axial bearing surface. Thus, the pump **2** includes a rotatable rotor assembly **700** that includes a bushing **800** wherein the bushing **800** is of single piece construction and includes a radial bearing surface **812** that restricts radial motion of the rotor assembly, a front axial bearing surface **822** that restricts forward motion of the rotor assembly **700**, and a rear axial bearing surface **824** that restricts rearward motion of the rotor assembly **700**.

Under some pump operating conditions, the impeller assembly **700** may experience a rear thrust force, pushing the impeller assembly **700** rearward and causing the rear surface **824** of the bushing **800** to rotatably engage the front surface **826** of the rear thrust washer **814**. Under other pump operating conditions, the impeller assembly **700** may experience a forward thrust force, pushing the impeller assembly **700** forward and causing the front surface **822** of the bushing **800** to rotatably engage the rear surface **828** of the front thrust washer **818**. The bushing **800** also includes one or more grooves **830** on the front face **822**, rear face **824** and inner surface **812**, which are connected. The radial bearing surface **812** of the rotor assembly **700** and the radial bearing surface **810** of the canister assembly front portion restrict radial motion of the rotor assembly **700**, and the first axial bearing surface **822** of the rotor assembly **700** and the first axial bearing surface **828** of the canister assembly front portion **404** restrict forward motion of the rotor assembly

700. In addition, the rotor assembly **700** further comprises a second axial bearing surface **824**, the canister assembly front portion further comprises a second axial bearing surface **826**, and the second axial bearing surface of the rotor assembly **824** and the second axial bearing surface **826** of the canister assembly front portion **404** restrict rearward motion of the rotor assembly **700**.

The canister **400***a* includes a thin cylindrical portion **422** having an inner surface **424** that is slightly larger than the outer surface **652** of the inner magnet assembly **600**, and having an outer surface **426** that is slightly smaller than the inner surface **738** along the thin cylindrical portion **714** of the impeller magnet sleeve **712**. The casing **100**, backplate **200**, and canister assembly **400**, with its canister **400***a* and nose cap **500**, all remain stationary, are sealingly connected, and together form a sealed fluid chamber rearward of the canister assembly **400**.

The magnet segments **646** of the drive magnet assembly or inner magnet assembly **600** are in axial alignment with the magnet segments **710** of the outer magnet assembly **705** of the rotatable rotor assembly or impeller assembly **700**. The stationary cylindrical portion **422** of the canister assembly **400** is located in a radial gap between the magnet segments **646** of the inner magnet assembly **600** and the magnet segments **710** of the outer magnet assembly **705** of the rotor assembly **700**. The alternating polarity of the magnet segments **646** creates an inner magnetic field, and the alternating polarity of the magnet segments **710** creates an outer magnetic field. These two magnetic fields synchronize together to provide a strong magnetic coupling torque between the inner magnet assembly **600** and the impeller assembly **700**, such that when the motor **6** is energized, it rotates the motor shaft **22**, which rotates the inner magnet assembly **600**, which in turn, rotates the impeller assembly **700**.

Referring to FIGS. **4** and **5**, the impeller **702** includes a plurality of vanes **740**. The casing **100** includes a discharge collector cavity **108** that is fluidly connected to the casing discharge port **102**. The rotation of the impeller vanes **740** causes a pumping action that moves liquid into the pump through the casing inlet port **104**, radially outward to the discharge collector cavity **108**, and out of the pump through the discharge port **102**. A portion of the vanes **740** of the rotor or impeller **702** extend forward in front of the front surface **509** of the nose cap **500** and inward to an inner diameter **744** that is smaller than an outer diameter **514** of the nose cap **500** of the canister assembly **400**.

Referring to FIG. **6***a*, the impeller **702** includes a rear wall **746** having a plurality of optional rear vanes **748**. As seen in FIG. **3**, the casing **100** includes a rear cavity **110** that is partially blocked from the discharge collector cavity **108** by the impeller rear wall **746**. During pump operation, rotation of the impeller **702** rotates the fluid within the rear cavity **110**. The optional rear vanes **748** enhance or increase the speed of rotation of the fluid within the rear cavity **110** of the casing **100** which experiences centrifugal force. The centrifugal force will tend to create a radial pressure gradient in the rear cavity **110**, where the pressure is somewhat proportional to the radius. This gradient will partially resist the pressure differential that promotes the recirculation path P, and will reduce the overall pressure within the rear cavity **110**, to that the net forward thrust on the rotor assembly or impeller assembly **700** is reduced.

When pump **2** is operating, the pumping action of the impeller vanes **740** creates a pressure differential within the pump **2**, such that the pressure at the inlet port **104** and in front of the nose cap **500** at the suction end of the pump **2** is lower than the pressure in the discharge collector cavity **108** and at the discharge port **102**.

As may be seen in FIG. **10** in a simplified view of the pump **2** without the drive magnet assembly or inner magnet assembly **600** and the power end drive components, the pump **2** includes a rather complex recirculation path P behind the impeller assembly **700**. The recirculation path P begins at the discharge collector cavity **108**, where the pressure is high, extends between stationary and rotating surfaces, and ends in front of the nose cap **500**, where the pressure is low. The recirculation path P is uniquely dynamic, because every portion of the path is bounded by a combination of a stationary surface and a rotating surface. This helps to avoid stagnation and clogging of the recirculation path P, which is used for lubrication and cooling of the pump components, such as the bushings and the canister assembly. The stationary surfaces are on the casing **100**, backplate **200**, and components of the canister assembly **400**, including the canister **400***a*, rear thrust washer **814**, bearing sleeve **806**, front thrust washer **818** and nose cap **500**. The rotating surfaces are on the rotatable rotor assembly or impeller assembly **700**. The recirculation path P includes a radial gap between the canister **400***a* and the sleeve **712** of the rotor assembly or impeller assembly **700**. The one or more grooves **830** on the front face **822**, rear face **824** and inner surface **812** of the bushing **800** also facilitate fluid passage.

The recirculation path P includes flow from the discharge collector cavity **108** past the outer edge of the impeller **702**. The fluid moves radially inward behind the impeller **702** and then further rearward behind the outer magnet assembly **705**. The fluid then moves forward along the canister portion extending through the radial gap between the canister and the outer magnet assembly **705**, and then the fluid passes radially inward over the canister to the bushing **800**. The fluid then passes through the grooves **830** that extend across the rear surface, inner surface and front surface of the bushing **800**. This example pump **2** includes four grooves **830** in the bushing **800**, and as a result, the fluid splits into four separate streams corresponding to the four grooves **830**. The four parallel paths continue through the grooves **830** to the front surface of the bushing **800**. The four flow paths come together at the front surface of the bushing **800** and then the fluid passes through a gap formed by the inner surface **727***b* of the impeller and both the outer surface of the front thrust washer **818** and the outer edges of the nose cap **500**, and to the low pressure area proximate the inlet port **104**.

Referring to FIGS. **11-13**, the same pump **2** of the first example is shown in a second example but connected to a different a rear end mechanical drive portion or power end and an adaptor. In this second example, the pump **2** is connected to a power end **900** and adapter **904** of a commercially available non-magnetically driven rotodynamic pump having a dynamic seal that is designed in accordance with dimensions specified in a pump industry standard, such as, for example, a Goulds 3196 Pump, made by ITT Goulds Pumps of Seneca Falls, N.Y., which is designed to meet the dimensioned required in industry standard ASME B73.1. This also applies to industry standard ISO 5199. The casing **100** is configured to be mounted in a stationary position and includes a rear face **106** that is connected to a flange **907** of the adapter **904** by use of a plurality of fasteners **10** that pass through apertures **912** in the flange **907** and engage threaded holes in the casing rear face **106**.

In this second example, however, the pump **2** further includes an inner magnet assembly **600** that includes an inner ring **640** which is connected directly to a shaft **902** of the power end **900**. The inner ring **640** has a central threaded aperture **642** and the power end shaft **902** has a mating externally threaded front portion **922**, which is used to connect the inner ring **640** to the power end shaft **902**. Thus, the example magnetically driven pump **2** can be substituted in place for a dynamically sealed pump and will provide or accommodate the same mounting dimensions that are shown in FIG. **11** as including: the horizontal distance F between the front and rear mounting feet; the vertical distance D from the bottom of the front mounting feet to the center of the motor shaft **902** and center of the flange for the inlet port **104** at the front of the pump **2**; the vertical distance X from the center of the motor shaft **902** and center of the flange for the inlet port **104** at the front of the pump **2** to the top surface of the flange for the discharge port **102**; the horizontal distance from the center of the discharge port **102** to the front of the flange for the inlet port **104**; the horizontal distances E**1** from the center of the inlet port **104** to the center of the mounting holes of the front mounting feet; the diameter H of the mounting holes in the front mounting feet; and the overall length CP of the pump **2** and power end.

Turning to FIGS. **14-21**, a third example pump **1002** is shown. The third example pump **1002** happens to be a magnetically driven, positive-displacement gear pump. The third example pump **1002** includes a casing **1100** that includes a front portion **1100***a* and a rear portion **1100***b* and a central portion **1100***c*. The casing portions may be separate components that are connected together or portions may be formed integrally, such as by casting. The casing **1100** is configured to be mounted in a stationary position via mounting feet on the central portion **1100***c*. The casing **1100** also has a discharge port **1102** and an inlet port **1104**. In this third example, the discharge port **1102** and inlet port **1104** both are radially facing, although alternative configurations may be utilized. The casing **1100** may be constructed of rigid materials, such as steel, stainless steel, cast iron or other metallic materials, or structural plastics or the like.

The rear portion **1100***b* of the casing **1100** includes an opening **1107** that receives one or more bushings or bearings **1120**, shown in the present example in the form of bearings. Also within the rear portion **1100***b* is a shaft **1130**. The shaft **1130** has a drive end **1132** that may be coupled to a driver (not shown), such as an electric motor or the like, that causes the shaft **1130** to rotate. As such, the example shaft **1130** is supported by the bushings or bearings **1120** and is free to rotate within the opening **1107** of the rear portion **1100***b* of the casing **1100**.

The shaft **1130** may be constructed of rigid materials, such as steel, stainless steel, cast iron or other metallic materials, or structural plastics or the like. The shaft **1130** also may have a magnet receiving end **1134** that may include one or more holes **1136**, which in this example are threaded, but it will be understood that other configurations may be used for connecting components to the magnet receiving end **1134**.

An example rotatable drive magnet assembly or inner magnet assembly **1200** is attached to the magnet receiving end **1134** of the shaft **1130**. The inner magnet assembly **1200** may include an inner ring **1210** having a generally cylindrical shape, one or more fasteners **1220** for connection to the receiving end **1134**, a plurality of (two or more) inner magnet segments **1230** and an optional inner magnet sleeve **1240**. The optional inner magnet sleeve **1240** may provide additional attachment force to hold the inner magnet segments **1230** to an outer surface **1211** of the inner ring **1210** and may provide protection of the inner magnet segments **1230** from corrosion or damage. The inner magnet sleeve **1240** may be constructed of rigid materials, but preferably is constructed of a material with very low magnetic permeability, such as stainless steel or the like. The method of connection for the inner magnet segments **1230** may be via adhesive, mechanical fasteners or other suitable means of connection. The magnet segments **1230** are radially charged and are positioned with alternating polarity, so as to create a magnetic field directed radially outward.

The example inner ring **1210** may have a web **1250** that in this example engages the magnet receiving end **1134** of the shaft **1130**, and one or more holes **1260** that align with holes **1136** in the magnet receiving end **1134** of the shaft **1130** and receive the fasteners **1220**. In the present example, the inner ring **1210** may be connected to and rotate with the magnet receiving end **1134** of the shaft **1130**. The inner ring **1210** may be constructed of rigid materials, but is preferably constructed of a material with high magnetic permeability, such as iron, carbon steel or the like. It also will be understood that the inner ring **1210** may be connected to the shaft **1130** in alternative ways.

The casing **1100** includes an opening **1109**, which in this example is in the central portion **1100***c*. The opening **1109** receives a canister assembly **1300** that is intended to be stationary. The canister assembly **1300** may be constructed of multiple pieces or may be of an integral, one-piece construction. The canister assembly **1300** may be constructed of rigid materials. It will be appreciated that common materials may be used, such as stainless steel, or low conductivity metals, such as alloy C-22 or alloy C-276, and it could be advantageous to use materials having very low electrical conductivity, such as silicon carbide, ceramic, polymers or the like. The stationary canister assembly **1300** includes a canister **1301** having a rear flange **1302** that extends radially outward and is held between the connection of the rear portion **1100***b* to the central portion **1100***c* of the casing **1100**. A rear canister seal **1310** creates a leak-tight connection between the radial rear flange **1302** of the canister **1301** and the central portion **1100***c* of the casing **1100**. The rear canister seal **1310**, may be in the form of static seal having a resilient O-ring shape, or a preformed or liquid gasket or the like, and preferably is constructed of an elastomeric material such as rubber or the like.

The canister **1301** of the canister assembly **1300** also includes a first cylindrical portion **1303** extending forward from the rear flange **1302** to a central radially extending portion **1304** that extends outward from the first cylindrical portion **1303** to a second cylindrical portion **1305** that extends further forward and is closed at the forward end by an end wall **1306**. The end wall **1306** is set back from the front end of the second cylindrical portion **1305**, forming a recess **1307** at the front of the canister **1301**.

The canister assembly **1300** also includes a nose cap **1330** having a rear portion **1331** that engages the recess **1307** at the front of the canister **1301**. The nose cap **1330** of the canister assembly **1300** also has a flange **1332** that extends radially outward. A rear surface **1334** of the flange **1332** provides a first or forward axial bearing surface of the canister assembly **1300**. The central radially extending portion **1304** of the canister **1301** has a front surface **1308** that provides a second or rearward axial bearing surface of the canister assembly **1300**. The nose cap **1330** may be constructed of rigid materials, such as steel, stainless steel, cast iron or other metallic materials, or structural plastics or the like. A front canister seal **1320**, such as in the form of static seal having a resilient O-ring shape, or a preformed or liquid gasket or the like, creates a leak-tight connection between the canister **1301** and the nose cap **1330**, and may be constructed of similar materials to those mentioned with respect to the rear seal **1310**. The stationary canister assembly **1300** separates an internal fluid chamber within the pump **1002** from the inner magnet assembly **1200**. It also will be appreciated that any of the bearing surfaces of the canister assembly **1300**, such as the radial bearing surface provided by the second cylindrical portion **1305**, the first or forward axial bearing surface provided by the rear surface **1334** of the flange **1332** of the nose cap **1330**, and the second or rearward axial bearing surface provided by the front surface **1308** of the central radially extending portion **1304** of the canister **1301** alternatively could be provided by separate pieces, such as in the first example pump **2**.

The front portion **1100***a* of the casing **1100** has a rear face that is sealed by a gasket **1108** to a front face of the central portion **1100***c* and closes the opening **1109** in the central portion **1100***c*. The gasket **1108** may be in the form of a static seal, such as a preformed or liquid gasket or the like, or an O-ring, and creates a leak-tight connection between the front portion **1100***a* and central portion **1100***c*, and may be constructed of similar materials to those mentioned with respect to the other seals. In this example, the front portion **1100***a* also has an inner surface **1109***a* that generally is aligned with the opening **1109** of the central portion **1100***c* of the casing **1100**. The front portion **1100***a* may be constructed of rigid materials, such as steel, stainless steel, cast iron or other metallic materials, or structural plastics or the like.

The front end of the central portion **1100***c* has one or more holes **1113**, which in this example are threaded. The front portion **1100***a* is connected to the central portion **1100***c* by one or more fasteners **1360**. In the present example, an elongated shaft portion of the one or more fasteners **1360**, which in this example is threaded, is assembled through one or more holes **1106** in the front portion **1100***a* and is installed in the one or more holes **1113** in the front of the central portion **1100***c* of the casing **1100**. It also will be understood that the front portion **1100***a* may be connected to other portions of the casing **1100** in alternative ways.

The nose cap **1330** of the canister assembly **1300** includes a front face **1333** that engages the front portion **1100***a*. The nose cap **1330** also includes a front gear support extension **1336**, from which a further nose cap support extension **1338** extends. At least a portion of the nose cap support extension **1338** is received by an opening **1112** in the front portion **1100***a*. The front nose cap support extension **1338** of the canister nose cap **1330** may include an alignment surface or shape that engages with a complementary surface or shape within the front portion **1100***a*, such that when the nose cap support extension **1338** is received in the opening **1112** of the front portion **1100***a*, the canister assembly **1300** is supported at its front end by the front portion **1100***a* of the casing **1100** and the engagement of the alignment surface or shape prevents relative rotation between nose cap **1330** and the front portion **1100***a*. It will be understood that alternative methods and configurations may be used to prevent relative rotation between the respective components, so that the canister assembly **1300** remains stationary. Although not required, an optional seal, such as in the form of static seal having a resilient O-ring shape, or a preformed or liquid gasket or the like, may be located between the nose cap front portion **1100***a* to prevent pumped fluids from entering the opening **1112** in the front portion **1100***a*. Such a seal may be constructed of similar materials to those mentioned with respect to the other seals.

A rotatable rotor assembly or outer gear assembly **1500** includes a rotor **1501** having an outer gear **1510** at a forward end and an opening **1520** at the rearward end that receives an outer ring **1530**, a plurality of (two or more) outer magnet segments **1540**, and an optional inner magnet sleeve **1550**. In this way, the rotor assembly **1500** includes a rear opening **1520** having an inner wall surface **1521** to which a plurality of magnet segments **1540** is connected. The rotor **1501** may be constructed of rigid materials, such as steel, stainless steel, cast iron or other metallic materials, or structural plastics or the like. The outer ring **1530** may be constructed of rigid materials, but preferably is constructed of a material with high magnetic permeability, such as iron, carbon steel or the like. The outer ring **1530** is connected in the opening **1520**, which may be accomplished by various means, including by interference fit, adhesive, welding, the use of fasteners or the like.

The outer ring **1530** includes an inner surface to which a plurality of (two or more) outer magnet segments **1540** are connected. It will be appreciated that the quantity of outer magnet segments **1540** should be equal to the quantity of the inner magnet segments **1230** that are connected to the inner ring **1210**. The method of connection for the outer magnet segments **1540** may be via adhesive (preferred), mechanical fasteners or other suitable means of connection. The outer magnet segments **1540** are magnetically radially charged and are positioned with alternating polarity, so as to create a magnetic field directed radially inward. The optional inner magnet sleeve **1550** may provide additional attachment force to hold the outer magnet segments **1540** to the outer ring **1530** and may provide protection of the outer magnet segments **1540** from corrosion or damage.

The stationary first cylindrical portion **1303** of the canister assembly **1300** is located in a radial gap between the magnet segments **1230** of the inner magnet assembly **1200** and the magnet segments **1540** of the rotatable rotor assembly or outer magnet assembly **1500**. The magnet segments **1230** of the inner magnet assembly **1200** also are in axial alignment with the magnet segments **1540** of the rotor assembly or outer magnet assembly **1500**. The stationary first cylindrical portion **1303** of the canister assembly **1300** is located in a radial gap between the magnet segments **1230** of the inner magnet assembly **1200** and the magnet segments **1540** of the outer magnet assembly of the rotor assembly **1500**. The alternating polarity of the magnet segments **1230** creates an inner magnetic field, and the alternating polarity of the magnet segments **1540** creates an outer magnetic field. These two magnetic fields synchronize together to provide a strong magnetic coupling torque between the inner magnet assembly **1200** and the rotating rotor assembly **1500**. In addition, the canister assembly **1300** includes a front portion extending from the first cylindrical portion, which in this example also includes a second cylindrical portion **1305** which essentially extends from the first cylindrical portion and includes a radial bearing surface, as well as a nose cap **1330**, which includes a first axial bearing surface **1334** on the rear of the flange **1332**.

The rotatable rotor assembly **1500** is positioned within the central portion **1100***c* and front portion **1100***a* of the casing **1100** and includes a rotor bushing **1560**. The rotor **1501** having the outer gear **1510** may be constructed of rigid materials, such as steel, stainless steel, cast iron or other metallic materials, or structural plastics or the like. The rotor bushing **1560** includes a front surface **1562** that provides a first or forward axial bearing surface and a rear surface **1564** that provides a second or rearward axial bearing surface. The rotor bushing **1560** further includes an inner wall surface **1566** that serves as a central cylindrical opening for the rotor assembly **1500** and provides a radial bearing surface for the rotor assembly **1500**.

The inner surface **1566** of the bushing **1560** of the rotor assembly or outer gear assembly **1500** provides a radial bearing surface that slidingly rotates on and is supported by the second cylindrical portion **1305** of the canister **1301** of the canister assembly **1300**. The first or forward axial bearing surface provided by the front surface **1562** of the bushing **1560** slidingly rotates against or engages the first or forward axial bearing surface provided by the rear surface **1334** of the flange **1332** of the canister assembly **1300**. The second or rearward axial bearing surface provided by the rear surface **1564** of the bushing **1560** slidingly rotates against or engages the second or rearward axial bearing surface provided by the front surface **1308** of the central radially extending portion **1304** of the canister **1301** of the canister assembly **1300**. Thus, the bushing **1560** is of single piece construction and provides all of the bearing surfaces for the rotor assembly **1500**.

Indeed, the radial bearing surface **1566** of the rotatable rotor assembly **1500** and the radial bearing surface provided by the outer surface of the second cylindrical portion **1305** of the canister assembly front portion restrict radial motion of the rotor assembly **1500**, and the first axial bearing surface **1562** of the rotor assembly **1500** and the first axial bearing surface **1334** of the nose cap **1330** restrict forward motion of the rotor assembly **1500**. In addition, the rotor assembly **1500** further comprises a second axial bearing surface **1564**, the canister assembly front portion further comprises a second axial bearing surface **1308**, and the second axial bearing surface of the rotor assembly **1564** and the second axial bearing surface **1308** of the front portion of the canister assembly **1300** restrict rearward motion of the rotor assembly **1500**.

A rotatable drive magnet assembly or inner gear assembly **1600** includes inner gear **1610** that is positioned within the front portion **1100***a* of the casing **1100**. The inner gear **1610** may be constructed of rigid materials, such as steel, stainless steel, cast iron or other metallic materials, or structural plastics or the like. Although not required, the inner gear assembly **1600** also may include an optional inner gear bushing **1620**, which has an outer surface **1622** that may be connected to an inner surface **1612** of the inner gear **1610** by various means, including by interference fit, adhesive, welding, the use of fasteners or the like. The inner gear bushing **1620** also has an inner surface **1624** that provides a radial bearing surface for the inner gear **1610** as it slidingly rotates on the front gear support extension **1336** of the nose cap **1330** of the canister assembly **1300**.

Pump operation comes from rotational energy that is supplied by a driver (not shown), such as an electric motor or the like, that is connected to the drive end drive end **1132** of the shaft **1130**. Thus, rotation of a driver or motor that is connected to the drive end **1132** causes the shaft **1130** to rotate. The inner magnet assembly **1200** is connected to, and therefore, rotated by the shaft **1130**. The radially outward magnetic field of the inner magnet segments **1230** rotates along with inner magnet assembly **1200**. In turn, the radially outward magnetic field of the inner magnet segments **1230** interacts with the radially inward magnetic field of the outer magnet segments **1540**, such that it drives the rotor assembly or outer gear assembly **1500** to rotate synchronously with inner magnet assembly **1200**, even though there is no physical contact between the outer gear assembly **1500** and the inner magnet assembly **1200**.

The outer gear **1510** includes a plurality of (in this instance three or more) teeth **1517** that mesh with a plurality of teeth **1613** of the inner gear **1610**. Rotation of the outer gear assembly **1500** causes engagement of the surfaces of the outer gear teeth **1517** with the surfaces of the inner gear teeth **1613**, thereby causing the inner gear assembly **1600** to rotate.

The front portion **1100***a* of the casing **1100** provides a pumping cavity that is connected to a discharge port **1102** and an inlet port **1104**. As the outer gear assembly **1500** and inner gear assembly **1600** rotate, the unmeshing of their teeth **1517** and **1613**, respectively, causes an expanding first pumping pocket that pulls fluid into it from the inlet port **1104**. As the outer gear assembly **1500** and inner gear assembly **1600** rotate further, the first pumping pocket moves clockwise until the teeth **1517** and **1613**, respectively, begin to remesh, which causes the pumping pocket to collapse, forcing the fluid to be discharged out of the pump **1002** through discharge port **1102**.

When pump **1002** is operating, the pumping action creates a pressure differential within the pump **1002**, such that the pressure at the inlet port **1104** proximate the inner gear **1610** and nose cap **1330** at the suction end of the pump **1002** is lower than the pressure in the discharged fluid at the discharge port **1102**. As may be seen in FIG. **21** in a simplified view of the pump **1002** without the inner magnet assembly **1200**, the rear portion **1100***b* of the casing **1100**, or the power end drive components, the pump **1002** includes a rather complex recirculation path P' that extends behind the rotor assembly or outer gear assembly **1500**. The recirculation path P' begins at the discharge portion of the casing **1100** that forms the discharge port **1102**, where the pressure is high, extends between stationary and rotating surfaces, and ends in front of the nose cap **1300**, where the pressure is low.

The recirculation path P' is uniquely dynamic, because every portion of the path is bounded by a combination of a stationary surface and a rotating surface. This helps to avoid stagnation and clogging of the recirculation path P', which is used for lubrication and cooling of the pump components, such as the bushings and the canister assembly. The stationary surfaces are on the casing **1100** and components of the canister assembly **1300**, including the radial rear flange **1302**, the first cylindrical portion **1303**, the central radially extending portion **1304**, the second cylindrical portion **1305**, and the nose cap **1330**. The rotating surfaces are on the rotor assembly or outer gear assembly **1500** and the inner gear assembly **1600**.

The recirculation path P' includes a longitudinal groove **1122** in the discharge side of the front portion **1100***a* of the casing that allows fluid to pass around a forward portion of the rotor assembly or outer gear assembly **1500**, which otherwise has a close clearance fit with the front portion **1100***a*. The outer diameter of the rotor assembly **1500** is reduced rearward of the front portion, increasing the clearance between the rotor assembly **1500** and the central portion **1100***c* of the casing **1100**. When the fluid from the groove **1122** in the front portion **1100***a* enters this area of greater clearance, it spreads out all the way around the rotor **1501** and into a cylindrical gap between the rotor assembly **1500** and the central portion **1100***c* of the casing **1100**, and continues to move rearward. The recirculation path P' continues behind the rotor assembly **1500** and along the radial rear flange **1302** of the canister **1301**, then moving forward along the first cylindrical portion **1303** and radially inward along the central radially extending portion **1304** of the canister **1301** and the rear surface **1564** of the bushing **1560** that provides the second or rearward axial bearing surface of the rotor assembly **1500**. The rear surface **1564** of the bushing **1560** has a close clearance fit to the rear flange **1302**, but the rear surface **1564** also includes a plurality of grooves **1570** that extend across surfaces of the bushing **1560**, including the rear surface **1564** that provides a second or rearward axial bearing surface, inner surface **1566** that provides a radial bearing surface, and front surface **1562** that provides a first or forward axial bearing surface of the bushing **1560**. This example pump **1002** includes four grooves **1570** in the bushing **1560**, and as a result, the fluid splits into four separate streams corresponding to the four grooves **1570** as it passes over the axial and radial bearing surfaces of the bushing **1560**. The four parallel paths continue through the grooves **1570** to the front surface **1562** of the bushing **1560**. The four flow paths from the grooves **1570** come together at the front surface **1562** and meet an outer corner of the flange **1332** of the nose cap **1330**, where a small donut shaped cavity **1574** is formed by a circumferential groove **1576** in the inner surface **1572** of the rotor **1501**, a circumferential groove on the outer rear corner of the flange **1332** of the nose cap **1330**, and a circumferential groove **1578** on the outer front edge of the bushing **1560**. Continuing in the path P', the radial flange **1332** of the nose cap **1330** has a close clearance fit with the inner surface **1572** of the rotor, but fluid is permitted to pass through a groove **1340** that extends longitudinally along the outer edge of the flange **1332** and then radially inward across the front face **1333** of the nose cap **1330**. The groove **1340** leads the fluid flow to a flat surface **1342** in the front gear support extension **1336**, which permits fluid to flow forward between the front gear support extension **1336** and the inner gear bushing **1620**, to a groove **1124** in the front portion **1100***a* of the casing **1100**. This further groove **1124** allows the fluid to flow through to the suction side at the inlet port **1104**, completing the recirculation path P' of the pump **1100**.

From the above disclosure, it will be apparent that pumps constructed in accordance with this disclosure may include a number of structural aspects that provide advantages over conventional constructions, depending upon the specific design chosen.

It will be appreciated that pumps constructed in accordance with the present disclosure may be provided in various configurations. Any variety of suitable materials of construction, configurations, shapes and sizes for the components and methods of connecting the components may be utilized to meet the particular needs and requirements of an end user. Indeed, pumps in accordance with the present disclosure may include interior surfaces that are constructed of specific materials and/or have particular surface finishes wherein the interior surfaces permit use of the pumps in hygienic applications where microbial growth must be prevented. It will be apparent to those skilled in the art that various modifications can be made in the design and construction of such pumps without departing from the scope or spirit of the claimed subject matter, and that the claims are not limited to the preferred embodiment illustrated herein. It also will be appreciated that some aspects of the example embodiment are discussed in a simplified manner and the aspects may be capable of being implemented in rotodynamic pumps, positive-displacement pumps, and whether such pumps include dynamic seals between rotating parts or are magnetically driven.

The invention claimed is:

1. A magnetically driven pump comprising:

a casing having a front portion, a rear portion, a discharge port and an inlet port;

a rotor assembly further comprising a rear opening having an inner wall surface and having a plurality of magnet segments connected to the inner wall surface, a central cylindrical opening having an inner wall surface that provides a radial bearing surface, a first axial bearing surface, and a second axial bearing surface;

an inner magnet assembly further comprising an inner ring and a plurality of magnet segments connected to an outer surface of the inner ring and being in axial alignment with the magnet segments of the rotor assembly;

a canister assembly further comprising a cylindrical portion disposed within a radial gap between the magnet segments of the inner magnet assembly and the magnet segments of the rotor assembly, and a front portion extending from the cylindrical portion and having a radial bearing surface, a first axial bearing surface, and a second axial bearing surface;

wherein the radial bearing surface of the rotor assembly and the radial bearing surface of the canister assembly front portion restrict radial motion of the rotor assembly, the first axial bearing surface of the rotor assembly and the first axial bearing surface of the canister assembly front portion restrict forward motion of the rotor assembly, and the second axial bearing surface of the rotor assembly and the second axial bearing surface of the canister assembly front portion restrict rearward motion of the rotor assembly.

2. The pump according to claim **1**, wherein the canister assembly front portion is spaced apart from the casing front portion.

3. The pump according to claim **1**, wherein the canister assembly front portion is supported by the casing front portion.

4. The pump according to claim **1**, wherein the pump is a rotodynamic pump and the rotor assembly further comprises an impeller.

5. The pump according to claim **1**, wherein the pump is a positive-displacement gear pump and the rotor assembly further comprises an outer gear.

6. The pump according to claim **1**, further comprising:

a recirculation path that extends from the casing discharge port, across the radial bearing surface of the rotor assembly, across the first and second axial bearing surfaces of the rotor assembly, across the cylindrical portion of the canister assembly, and to the casing inlet port;

wherein when the rotor assembly rotates within the casing and relative to the canister assembly, all portions of the recirculation path include at least one stationary surface of the casing or canister assembly that is opposed to at least one surface of the rotor assembly.

7. The pump according to claim **6**, wherein the pump is a rotodynamic pump and the rotor assembly further comprises an impeller.

8. The pump according to claim **6**, wherein the pump is a positive-displacement gear pump and the rotor assembly further comprises an outer gear.

9. A magnetically driven rotodynamic pump comprising:

a stationary casing having a discharge port, an inlet port, a mounting foot and a rear mounting flange;

an inner magnet assembly having an inner ring and a plurality of magnet segments;

an impeller assembly comprising an impeller, at least one radial bearing surface, at least one axial bearing surface and a plurality of magnet segments;

wherein the casing, inner magnet assembly and impeller assembly are configured and dimensioned to be assembled to a power end and adapter of a commercially available non-magnetically driven rotodynamic pump having a dynamic seal that is designed in accordance with dimensions specified in a pump industry standard, such that when assembled, the sizes and locations of the casing discharge port, the casing inlet port, the casing mounting foot, and the power end and adapter all meet the dimensions specified in the standard.

10. The pump according to claim **9**, wherein the pump industry standard is ASME B73.1.

11. The pump according to claim **9**, wherein the pump industry standard is ISO 5199.

12. A magnetically driven rotodynamic pump comprising:

a stationary casing having a front portion, a rear portion, a discharge port and an inlet port;

a stationary canister assembly connected to the stationary casing;

the stationary canister assembly further comprising a canister and a stationary nose cap connected to the canister and having an outer diameter, a rear axial bearing surface and a front surface;

a rotatable rotor assembly further comprising an impeller having a plurality of front vanes;

wherein a portion of the impeller vanes extend forward of the nose cap front surface and inward to an inner diameter that is smaller than the outer diameter of the nose cap.

13. A pump comprising:

a stationary casing having a front portion, a rear portion, a discharge port and an inlet port;

a rotor assembly further comprising a bushing wherein the bushing is of single piece construction and includes a radial bearing surface that restricts radial motion of the rotor assembly, a front axial bearing surface that restricts forward motion of the rotor assembly, and a rear axial bearing surface that restricts rearward motion of the rotor assembly.

14. The pump according to claim **13**, wherein the pump is magnetically driven, the rotor assembly further comprises a plurality of magnet segments, the pump further comprises a drive magnet assembly having a plurality of magnet segments in axial alignment with the magnet segments of the rotor assembly, and the pump further comprises a canister assembly having a cylindrical portion disposed within a radial gap between the magnet segments of the rotor assembly and the magnet segments of the drive magnet assembly.

15. The pump according to claim **13**, wherein the pump further comprises a rotodynamic pump and the rotor assembly further comprises an impeller.

16. The pump according to claim **13**, wherein the pump further comprises a positive-displacement gear pump and the rotor assembly further comprises an outer gear.

17. The pump according to claim **14**, wherein the pump further comprises a rotodynamic pump and the rotor assembly further comprises an impeller.

18. The pump according to claim **14**, wherein the pump further comprises a positive-displacement gear pump and the rotor assembly further comprises an outer gear.

19. A pump comprising:

a stationary casing having a front portion, a rear portion, a discharge port and an inlet port;

a rotor assembly further comprising a rotor that includes a central opening extending axially through the rotor and having a step proximate one end of the central opening, a separate rotor ring, and a separate bushing;

wherein the separate bushing fits inside the rotor central opening and is axially held in place by the separate rotor ring and the step in the central opening of the rotor when the separate rotor ring is connected to the rotor.

20. The pump according to claim **19**, wherein the pump is magnetically driven, the rotor assembly further comprises a plurality of magnet segments, the pump further comprises a drive magnet assembly having a plurality of magnet segments in axial alignment with the magnet segments of the rotor assembly, and the pump further comprises a canister assembly having a cylindrical portion disposed within a radial gap between the magnet segments of the rotor assembly and the magnet segments of the drive magnet assembly.

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